Watershed Protection

Techniques

A Quarterly Bulletin on Urban Watershed Restoration and Protection Tools
Vol. 1, No. 2 — Summer, 1994

A Publication of the

CENTER FOR WATERSHED PROTECTION

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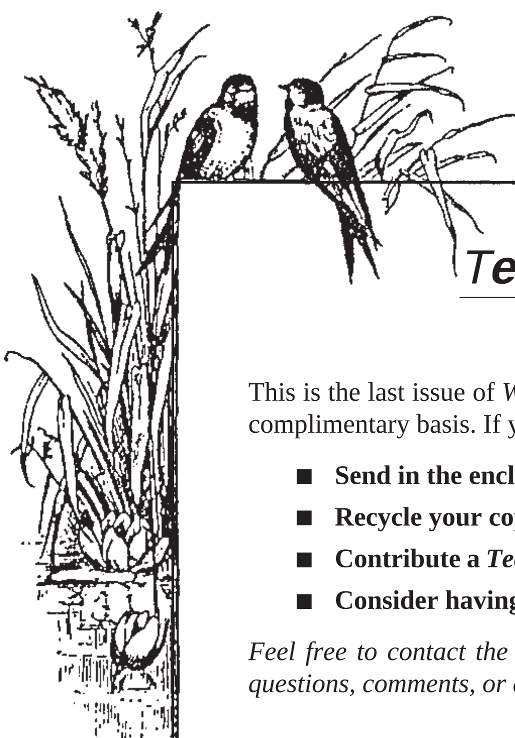

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FEATURE WETLAND PLANT

Broad-leaf Arrowhead
Sagittaria latifolia

The broad-leaf arrowhead ranges from New Brunswick to southern British Columbia, south to Florida, California, and Mexico. The plant grows up to four feet with a tall stalk raising from large basal leaves with white flowers with yellow centers in whorls of three.

Habitat communities include fresh tidal marshes, nontidal marshes, swamps, forested seeps, and borders of streams, lakes, and ponds. Growth is rapid, over one foot per year in unconsolidated sediment.

Rhizomes produce starchy tubers often referred to as "duck potatoes." Muskrats, beavers, porcupines, geese, ducks, and other animals readily consume the tubers. Native Americans and European settlers also used the duck potato as a food source.

See Technical Note 24 for more information.

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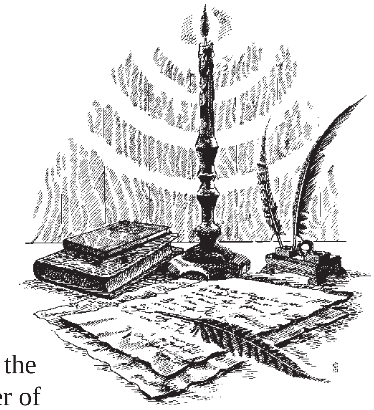
Submissions: Editors welcome submissions of *Technical Notes* on the performance of urban watershed restoration and protection tools. The only special criterion is that the performance of the technique must be tested in some manner (e.g., monitoring, field surveys, maintenance records). Additional submission information is presented on the inside back cover. Ideas concerning the *Feature Articles*, *Open Forum*, and *Resources* sections are also welcome. Please send all submission correspondence to Editor, Watershed Protection Techniques, 8630 Fenton Street, Suite 910, Silver Spring, MD 20910 or call the Editor at (301) 589-1890.

The quality of Techniques depends on readers becoming contributors

From the Editor's Desk



Techniques was launched with the conviction that watershed protection is not merely a new environmental fad but an emerging practice and a growing profession. It was explicitly designed to serve the thousands of environmental professionals that are engaged in the challenging task of protecting our nation's streams, lakes, and estuaries. Our basic editorial philosophy is to provide the practitioner with condensed summaries of proven and practical techniques that can adapted or applied in their own locale.

Launching a new publication is never an easy venture. Even so, we have been gratified by your response to the inaugural issue. The Center for Watershed Protection has received a great deal of positive feedback, in the form of hundreds of phone calls, letters, and better yet, SUBSCRIPTIONS. To become a self-sustaining publication, however, we still need 1,000 more individuals and organizations to subscribe by year's end.

This second issue is the last one that we can afford to distribute to you on a complimentary basis. If you want to continue to receive your quarterly issue of *Techniques*, please fill out and return the enclosed subscription card today. Your financial support is urgently needed to maintain the breadth and quality of the journal. After all, who would want to miss the third issue of *Techniques*? It will continue to provide the latest research on state of the art watershed protection measures, such as:

- the case for subdivision code reform;
- recent research on the links between watershed imperviousness and stream quality;
- pollutant removal performance of grassed swales, biofilters, and bioretention systems;
- groundwater impacts of rural septic systems;
- the use of cluster development to protect streams;
- urban stream restoration case studies; and
- a dozen more technical notes.

Reader Feedback

Your feedback helps to improve *Techniques* and we intend to incorporate your comments and ideas into the fabric of each issue. A number of readers detected perhaps our greatest editorial goof, which was to appeal for written contributions, yet to fail to include any instructions on how to do so. **Instructions for Contributors** have since been developed, and can be found on the inside back cover of this and succeeding issues. If you wish to submit a feature article, technical note, or open forum opinion, please refer to this discussion.

Other readers asked us to provide at least a few more feature articles in each issue that concisely summarize a body of research or review a series of practices. In response, we plan to include at least two Feature Articles in each issue, while still retaining about the same number of Technical Notes. Many readers also suggested that we try to make each issue more thematic in nature (by grouping a cluster of notes on the same topic in each issue). We plan do a better job in future issues. Finally, we have added a Feedback section to print comments, observations, and perspectives supplied by our readers in response to material that have appeared in *Techniques*. Please feel free to send in your thoughts and ideas.

If you want to continue to receive your quarterly issue of *Techniques*, please fill out and return the enclosed subscription card TODAY!

Perhaps the most frequent comment we heard about the first issue was "Can you keep it up?" (i.e., is there enough research out there on effective watershed protection and restoration techniques to keep filling up the pages of a quarterly journal?) Clearly, the answer to this question is YES, as witnessed by the hundreds of watershed research studies and demonstration projects that are currently underway in North America.

Sadly, though, many of these important studies are not widely printed or distributed. They end up, somewhat dog-eared, on a bookshelf, a grant file, or in the large stacks that clutter our desks. Important findings and conclusions remain unread and unavailable to practitioners elsewhere.

Your help in getting this practical knowledge into the light of day is needed. The value and quality of *Techniques* will ultimately depend on our READERS becoming CONTRIBUTORS. *Techniques* is intended to be the forum for technical exchange among watershed practitioners and environmental professionals from across the country. Please share your knowledge and research on effective watershed protection techniques with your colleagues!

— Tom Schueler

Special Note

As this second issue of *Techniques* was going to press, we were saddened to learn that the Center for Watershed Protection's president, Dr. Harvey Olem, was reported missing in Bolivia after the light plane he was travelling in lost contact with ground stations on May 7, 1994 between Teoponte and La Paz. Despite over nine weeks of intensive air and ground searches, no signs of the plane or its five passengers have been reported yet. Our thoughts and prayers are for Harvey's safe return, and the continued strength of his family through this trying ordeal.

At the time of his disappearance, Harvey was working with the World Bank and the Bolivian government as an environmental consultant. Harvey co-founded the Center for Watershed Protection in 1992, and has been instrumental in launching this nonprofit organization. He has also served as the publisher of the inaugural issue of *Techniques*.

A fund has been established to aid search and rescue efforts, and provide for the families of Dr. Olem and a Canadian colleague who was also on the plane, Peter Seidl. Donations can be sent to the Olem/Seidl Fund, c/o The Center for Watershed Protection, 8630 Fenton Street, Suite 910, Silver Spring, MD 20910.

Reader Feedback

■ Songbird Mortality in Tree Shelters

Several readers alerted us to a series of letters published in the *Chesapeake Bay Journal* that raised concerns about the use of tree shelters, as discussed in Technical Note 11 (Tree Shelters and Weed Control Increase Survivorship of Riparian Plantings). It has been reported that songbirds alight on the top of tree shelters and subsequently become trapped inside the tube and perish. Some workers suggest that this phenomenon can cause significant bird mortality, especially for bluebirds and other species that like to perch near open fields.

Other foresters respond that bird-trapping incidents in tree shelter tubes are quite rare, and might be avoided altogether by placing a fine-mesh screen at the top of the shelter tube. Apparently, some tree shelter manufacturers are redesigning their tree shelters to minimize the potential for songbird trapping

Do any of our readers have any field experience or insights into this problem?

■ Wetland Plantings on the Bench—Persistent but not Abundant

Technical Note 8, Persistence of Wetland Plantings Along the Aquatic Bench of Stormwater Ponds, reported on the work by Shenot (1993) in three stormwater ponds in Maryland. The Note concluded that planted species still persisted in 68% of the original planting zones after three years.

This conclusion, however, maybe somewhat misleading according to a further research by Shenot and Kangas (1994). They compared the abundance of planted species versus volunteer species at each planting zone and the pond's wetland community as a whole. A table that summarizes their most recent analysis is shown below.

Planted species as a percent of the total wetland plant community in three Maryland stormwater ponds. *(Shenot and Kangas, 1994)*

	In Planting Zone	Along Entire Bench
Sweetflag *(Acorus calamus)*	6.0	1.5
Arrow arum *(Peltandria virginia)*	<1.0	<1.0
Pickerelweed *(Pontederia cordata)*	19.3	1.7
Arrowhead *(Saggitaria latifolia)*	4.7	1.7
Lizard's tail *(Saururus cernus)*	0	0
Comm. 3-square *(Scirpus americanus)*	4.7	2.3
Soft stem bulrush *(Scirpus validus)*	23.0	5.3
Wild rice *(Zizania aquatica)*	51.0	4.5

The three most successful planted species (*Pontederia cordata*, *Scirpus validus*, and *Zizania aquatica*) were seldom the dominant wetland plant within their original planting zone. Despite some spread they were still a negligible component of the entire wetland community outside of the planting zones after three years. Shenot and Kangas suggest that competition from volunteer species and preferential waterfowl grazing may partly explain the results.

Clearly, the study demonstrates that planted wetland species may persist on the aquatic bench, but they may not always be the most abundant species. Further research on additional ponds and different planting techniques is needed to improve the effectiveness of plantings on the aquatic bench.

Reference

Shenot, J. and P. Kangas. 1994. Evaluation of Wetland Plantings in Three Stormwater Retention Ponds in Maryland. Proceedings Tampa Bay Conference on Wetland Restoration and Creation. May 5-8, 1994.

■ More Extensive and Standard Reporting in BMP Performance Monitoring Studies Urged

Editorial Board member Ben Urbonas (Urban Drainage and Flood Control District, Denver, CO) wrote to suggest that researchers include more than just pollutant removal efficiency numbers when reporting on performance monitoring studies of various urban best management practices. Of key interest are variables that describe critical watershed parameters, runoff characteristics, and BMP design geometry. Other important variables include the age and maintenance history of the BMP, and climatic data during the monitoring period.

Urbonas argues that such data is relatively easy to obtain, particularly when compared to the time and expense needed to collect actual performance monitoring data. Yet watershed parameters and design geometry are often crucial in interpreting the observed performance of the BMP being tested. Indeed, pollutant removal performance is seldom only a function of the type of BMP being monitored, but also by the character and runoff of its contributing watershed, and its internal design geometry.

Routine reporting of these variables in performance monitoring studies permits more standardized comparison of different results. Over time, reporting of these variables will enable other researchers and designers to better assess the key factors that influence pollutant removal in BMPs, and help place research findings in context of others. Standard reporting is also needed to provide assurance that localized research findings can be properly extended to other geographic and climatic areas.

A summary of key parameters that should be reported in BMP performance studies is being developed by Urbonas and his colleagues and should be published in *Techniques* later this year. The editors endorse this approach and encourage contributors to provide as much watershed and geometry data as possible when presenting their results.

■ Sorry — Wrong Number

The feature article on hydrocarbon hotspots (Techniques 1(1):3-5) included a box that listed several vendors that have developed new products for controlling hydrocarbon runoff from small development sites. We inadvertently provided the wrong address for the Stormceptor™ system developed in Canada.

The correct address and phone number is: Stormceptor Canada, Inc., 195 The West Mall, Suite 405, Etobicoke, Ontario, M9C 5K1. Telephone: 416/626-0840.

We apologize for any inconvenience this may have caused.

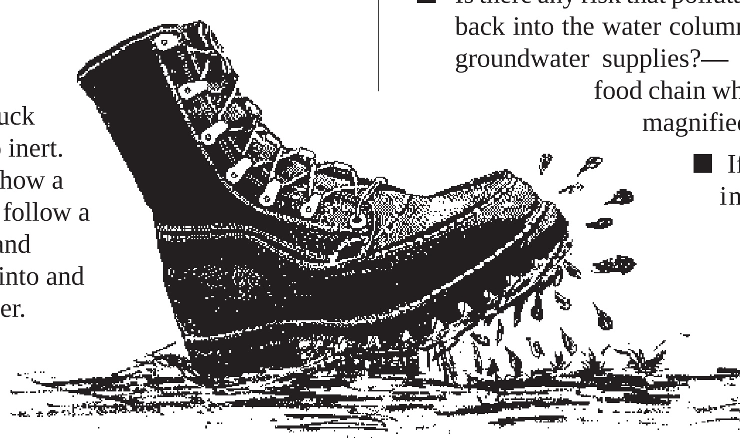
Muck deposition influences design and maintenance of stormwater ponds

Pollutant Dynamics of Pond Muck

Historically, most research on stormwater ponds has focused on the movement of pollutants into and out of the pond. This is quite understandable, as knowledge about inputs and outputs of pollutants helps to estimate pollutant removal performance. An impressive amount of input/output monitoring data has been collected; nearly 65 pond monitoring studies have been conducted in the U.S. and Canada.

Most of the monitoring studies have shown that stormwater ponds and wetlands are quite effective in trapping pollutants carried in urban stormwater. Much less is known, however, about the fate of stormwater pollutants once they are trapped in a pond. It is generally assumed that most of the pollutants eventually settle out to the pond bottom and form a muck layer. *[The term* **muck layer** *is used here to distinguish newly-deposited bottom sediments from the older parent soils that formed the original pond bottom.- ed.]*

The muck layer deepens as the pond ages. Pollutants may remain trapped within the muck layer until the entire layer is excavated during a pond clean-out. In most cases the muck is eventually dewatered, excavated, and applied back to the land surface. Research on bottom sediments in other shallow water systems, however, suggests that the muck layer may not be so inert. Figure 1 illustrates how a given pollutant can follow a number of diverse and complex pathways into and out of the muck layer.



Some runoff pollutants are transformed within the muck layer, while others are decomposed through chemical and microbial processes involved in sediment diagenesis. Indeed, diagenesis is often a key pathway for decomposition of organic matter and some nutrients. Alternatively, pollutants can migrate further below the muck layer and into the original soil profile. In some extreme cases, pollutants can travel into groundwater.

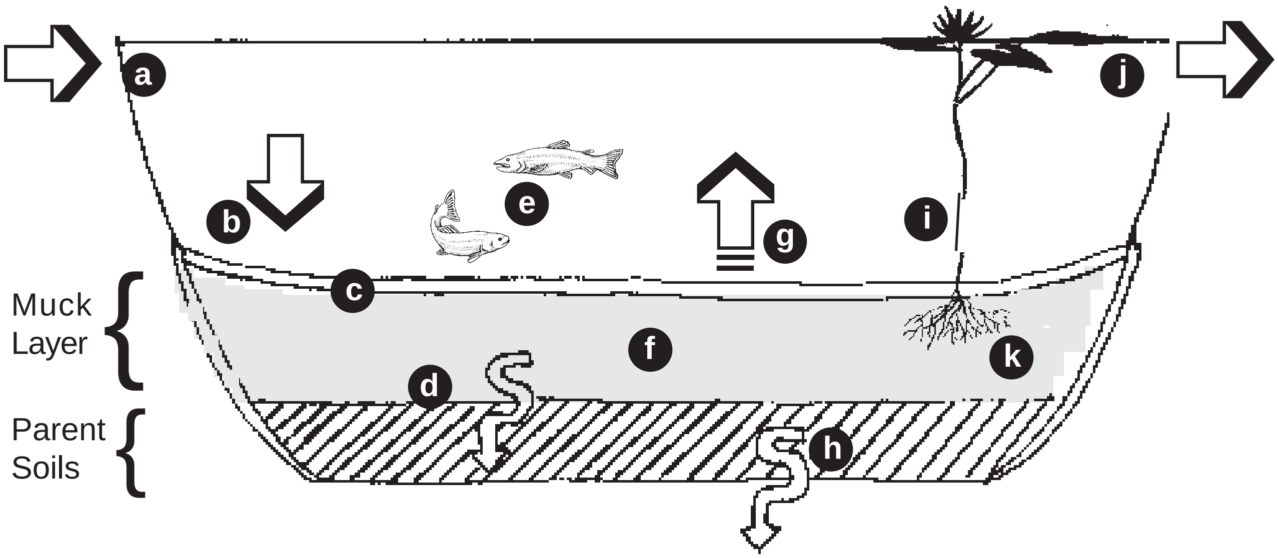
Alternatively, pollutants might enter the food chain while in the muck layer, either through uptake by wetland plants or by bottom feeding fish. Under the right conditions, some pollutants could also be released from the muck into the water column (where they could exit the pond during the next storm).

Pollutants can follow a number of diverse and complex pathways into and out of the muck layer

In this article, we examine the internal dynamics within the muck layer of stormwater ponds, based on an extensive review of research studies on the physical, chemical, and biological nature of the muck layer of over 50 stormwater ponds and wetlands. While it must be admitted that the study of muck is somewhat lacking in glamour, it can have many important implications for the design and operation of stormwater ponds and wetlands. Typical questions include:

- What is the average deposition rate of muck in ponds?
- After how many years of deposition will muck need to be removed?
- Can the deposition rate be used to calculate the size of the sediment forebay for a pond?
- How tightly are pollutants held in the muck layer?
- Is there any risk that pollutants could be released back into the water column? — or migrate into groundwater supplies?— or enter the aquatic food chain where toxicity might be magnified?
- If pollutants do remain in the muck layer, should muck be considered hazardous or toxic?
- Can muck be safely applied back on the land surface after it is cleaned out from the pond? — Or are more exotic and expensive methods needed to safely dispose of muck?
- Finally, the depth of accumulated muck generally represents the long term work of a pond in trapping pollutants. Can the characteristics of pond muck allow us to infer anything about the

Figure 1: A field guide to the muck layer



Pond muck represents a long term repository for the pollutants trapped within a stormwater pond. A pollutant, however, can take many different pathways through the mucklayer as shown in the diagram above.

a **Pollutant inflow.** Sediment, nutrients, trace metals, and hydrocarbons enter the pond during each storm. The total pollutant load delivered to the pond depends to some degree on land use. Some evidence exists that metal and hydrocarbon loads are significantly greater from watersheds draining roads or industrial areas.

b **Sediment Deposition.** A steady rain of sediment particles, attached pollutants, and algal detritus forms the muck layer over time. Field measurements indicate that the muck layer grows from 0.1 to 1 inch per year, with greater deposition noted near the inlet.

c **Muck Microlayer.** The uppermost layer of muck represents the recently deposited sediments and pollutants. Consequently, it is very high in organic matter and constantly worked over by microbes, worms and other organisms.

d **Downward Migration.** Most pollutants are tightly bound to sediment particles and remain fixed within the muck layer. Other pollutants can migrate downward into the subsoil via pore spaces between sediment particles.

e **Fish Bio-magnification.** Bottom feeding fish that dwell in larger ponds, such as carp and catfish, ingest detritus from the muck layer. Not much is known about pollutants accumulating in their tissues over time.

f **Sediment Diagenesis.** Organic matter and nutrients are gradually reduced and decomposed over time in the muck layer through a process known as sediment diagenesis. Diagenesis is a key pollutant removal pathway that combines physical, chemical, and biological processes within the sediment to slowly break down organic matter, in the presence or absence of oxygen.

g **Phosphorus Release.** In the summer, low oxygen levels near the bottom of pond can induce a “burp” of soluble phosphorus, ammonia, or methane back into the water column. The potential for this phenomena is greatest in deeper ponds in warmer latitudes.

h **Groundwater Migration.** Pollutants not tightly bound to the pond muck can migrate downward through sediment pore spaces and ultimately reach the water table. Soluble pollutants, such as chloride and nitrate, are the most mobile and have been reported to migrate outward from ponds into groundwater at modest levels. Most monitoring studies, however, reveal little if any risk of groundwater contamination from stormwater pond muck.

i **Wetland Plant Uptake.** The roots of wetland plants take up both nutrients and metals from the muck layer and transport them upward to tubers, stems, and leaves. At the end of the growing season, this above-ground plant matter often dies off. Some of the nutrients are released back into the pond, while others settle back to the muck layer as detritus.

j **Pollutant Export from the Pond.** Pollutants remaining in the pond’s water column will often flush out during the next storm event. Consequently, any pollutants that were released from the muck layer back into the water column may exit as well, thereby reducing the long term pollutant removal performance of the pond.

k **Sediment Clean-outs.** The ultimate removal of stormwater pollutants is accomplished when the muck layer is excavated from the pond and applied back on the land. This operation may need to be conducted every 25 to 50 years, depending on whether the pond has a forebay. Based on existing data and sediment quality criteria, pond muck does not usually constitute a toxicity hazard.

pollutant removal processes operating in ponds or the land uses that drain to it? Do pollutant concentrations "fingerprint" land uses?

To answer these questions, we reviewed bottom sediment chemistry data from 37 wet ponds, 11 detention basins, and two wetland systems, as reported by 14 different researchers. Although the studies covered a broad geographic range, almost 50% of the sites were located in Florida or the Mid-Atlantic states. Analysis was restricted to mean dry weight concentrations of the surface sediments that comprise the muck layer (usually the top 5 centimeters). The stormwater ponds ranged in age from 3 to 25 years.

The Nature of Pond Muck

The muck layer can be easily distinguished from the parent soils that comprise the pond's original bottom. Distinguishing features include the following:

- **a very "soupy" texture** — 57% moisture, Number of studies reporting (N) = 15;
- **a distinctive grey to black color**;
- **a high organic matter content** — nearly 6% volatile suspended solids on average (N=16);
- **a low density** (about 1.3 gms/cm^3); and
- **poorly-sorted sands and silts dominating the muck layer.**

Deposition of Muck

Muck essentially represents the bulk of all sediments and pollutants that have been historically trapped within a pond (excepting those that are microbially broken down into gaseous forms or those pollutants that migrate below the pond). Therefore, the long term deposition rate of the muck layer is of great interest.

The annual deposition rate can be easily calculated if the age of the pond and the depth of the muck layer are known. The depth of the muck layer is relatively easy to estimate in the field, due to its unique physical characteristics. Annual muck deposition rates on the order of 0.1 to 1.0 inch per year have been reported for a series of ponds in Florida.[23] These rates compare favorably with other pond sedimentation rates calculated at 0.5 inches/yr[6] and 0.8 inches/yr[19] utilizing different techniques.

The deposition rate of muck is not always the same throughout a pond, however. The greatest rates tend to be observed near the inlets of wet ponds, and to some extent, the outlets of detention basins.[9] In addition, muck deposition rates increase sharply for ponds that are small in relation to the contributing watershed areas and for ponds that located directly in streams.[6]

Nutrient Content of Pond Muck

As might be expected, the muck layer is highly enriched with nutrients (Table 1). Phosphorus concentration for the 23 studies reviewed averaged 583 mg/kg (range 110 to 1,936 mg/kg, N=23). Nearly all the nitrogen found in pond muck is organic in nature, with a mean concentration of 2,931 mg/kg (range 219 to 11,200, N=20). Nitrate is present in extremely small quantities, which may indicate that some denitrification is occurring in the sediments, or perhaps merely that less nitrate is initially trapped in muck.

Muck essentially represents the bulk of all sediments and pollutants that have been historically trapped within a pond.

In the entire pond data set, the nitrogen to phosphorus (N:P) ratio of the muck layer averages about 5 to 1, whereas the average N:P ratio for incoming stormwater runoff is typically around 7 to 1. This lower N:P ratio is not unexpected. Ponds are generally more effective in trapping phosphorus than nitrogen and the decay rate for nitrogen in the muck layer is generally thought to be more rapid than for phosphorus.[1]

Researchers have expressed concern that phosphorus trapped in the muck layer might be released back into the water column, particularly when oxygen levels are low in the summer. A number of investigators have observed hypoxic and even anoxic conditions near the muck layer in ponds as shallow as 5 feet deep.[6, 22]

An intriguing suggestion for possible sediment phosphorus release is evident in a handful of Florida ponds (Table 1). These ponds had unusually high N:P ratios of the muck layer, often in excess of 10 to 1. One explanation for the apparent depletion of phosphorus in the muck layer would be the mobilization and release of phosphorus from recurring anoxia over many years.

Still, most of the more Northern ponds, as well as many Southern ones, appear to retain most of the phosphorus deposited in the muck layer. For example, phosphorus levels in the muck layer are 2.5 to 10 times higher than the soils underlying the pond bottom. Also, muck layer phosphorus levels do not normally show a decrease as ponds grow older.

Trace Metal Content of the Muck Layer

The muck layer of stormwater ponds is heavily enriched with trace metals. This phenomenon is consistent with reported performance data (Table 2). Trace metal levels are typically 5 to 30 times higher in the muck layer, compared to parent soils. Trace metal levels in the muck layer also follow a consistent pattern and distribution, (zinc > lead >>

Table 1: Characteristics of the muck layer in wet stormwater ponds (mg/kg dry weight unless otherwise noted)

Location (Ref.)	Land Use	% Moisture	% Volatile Suspended Solids	Total Kjeldahl Nitrogen	Total Phosphorus	Nitrogen to Phosphorus Ratio	Hydro-carbons
FL (23)	Road	63	7.1	5180	510	10:1	
FL (23)	Road	77	10.2	4140	301	14:1	
FL (23)	Road	50	9.7	3110	1116	3:1	
FL (23)	Road	60	6.8	1130	100	11:1	
FL (23)	Road	52	6.5	2290	270	9:1	
FL (23)	Road	62	4.5	1440	370	4:1	
FL (23)	Road	65	4.8	2070	480	4:1	
FL (23)	Road	60	4.3	2110	110	20:1	
FL (23)	Road	76	10.4	11200	420	26:1	
FL (22)	Residential	33	2.4	889	292 #	3:1	
FL (3)	Road	64		2306 *	3863	0.6:1	
FL (11)	Residential		6.4	624	619	1:1	
FL (11)	Residential		1.1	256	389	0.7:1	
FL (11)	Commercial		4.1	5026	1936	3:1	
FL (16)	Road				1100		
VA (10)	Residential		4.3	828	232	4:1	
NZ (13)	Industrial			2471	995	3:1	12892
NZ (13)	Residential			5681	1053	5:1	2087
MN (14)	Residential	70	9.5		405		
MN (15)	Residential	32	4.8		606		
MN (3)	Road	51		3271	695	5:1	
CT (3)	Road	32		219	499	0.4:1	
MD (17)	Institutional			11000	917	12:1	474
	MEANS	**57**	**6.0**	**2931**	**583**	**5:1**	

* = Total Nitrogen
# = May have been influenced by fuel spill

tion of lead-free fuels over the last decade, with the consequent reduction in lead loadings delivered to the younger ponds.

The trace metal content of the muck layer happens to be directly influenced by the type of land use that drains to it (Table 3). Muck layers in stormwater ponds that drain residential areas had the lightest metal enrichment. Commercial sites were subject to slightly greater enrichment, particularly for copper, lead, and zinc. Ponds that primarily served roads and highways were highly enriched with metals, presumably due to the influence of automotive loading sources (e.g., cadmium, copper, lead, nickel, and chromium)

Although the muck layer is highly enriched with metals, it should not be considered an especially toxic or hazardous material.

Although the sample size was small (N=2), industrial catchments had, by far and away, the greatest level of trace metal enrichment in the muck layer of any land use. Clearly, further monitoring of heavily industrial catchments is warranted to confirm if muck enrichment represents a problem.

Most trace metals are very tightly fixed in the muck layer and do not migrate more than a few inches into the soil profile. Many researchers have examined soil cores to determine the distribution of trace metal concentration with depth. A consistent pattern is noted. Trace metal levels are at their maximum at the top of the surface layer, and then decline exponentially with depth. Eventually they reach normal background levels within 12 to 18 inches below the pond. Representative sediment metal profiles are shown in Figure 2.

Although the muck layer is highly enriched with metals, it should not be considered an especially toxic or hazardous material. For example, none of over 400 muck layer samples from any of the 50 ponds sites examined in this study exceeded current EPA's land application criteria for metals[8] (Table 2). In fact, metal levels in the muck layer are usually less than ten times higher than the national mean for agricultural soils in the U.S.[12] (Table 4).

Of perhaps greater interest is whether soluble metals can easily leach from the muck layer where they could exert a biological or groundwater impact. The capacity for metals to leach from sediments is mea-

Table 2: Trace metal content in the muck layer of 50 stormwater ponds and wetlands (mg/kg dry weight)

BMP	Location	(Ref.)	Land Use	Cadmium	Copper	Lead	Zinc	Nickel	Chromium
WP	FL	(22)	Residential	4.8	13	38.2	35.7	10.8	4.8
WP13	VA	(2)	Mix	3.2		45.3			25
WP	VA	(10)	Residential	0.8	17.2	48	78	12.2	
WP	NZ	(13)	Industrial		173	578	3171		
WP	NZ	(13)	Commercial		18.2	48.9	146		
WP9	FL	(23)	Road	15	28	374	161	52	61
WP	MD	(17)	Institutional	12	130	202	904		120
WP	MN	(14)	Residential			32.9			
WP	MN	(15)	Residential			17.0			
WP	OR	(4)	Institutional		60.2				
WP	CT	(3)	Road	0.4	19	39	53		13
WP	FL	(3)	Road	ND	13	125	105		31
WP	MN	(3)	Road	ND	57	139	261		51
WP	FL	(16)	Road	6	49	620	250		20
WP	FL	(11)	Residential	1.5	7	11	6	3	6
WP	FL	(11)	Residential	0.6	2	12	11	4	12
WP	FL	(11)	Commercial	2.7	6	42	103	6	11
SM	MN	(14)	Residential			82			
SM	MN	(15)	Residential			56			
DPSM	MD	(9)	Industrial	12	140	400	1098		
EDP	MD	(9)	Residential	0.4	8	223	45		
DP	VA	(9)	Commercial	1.7	30	748	202		
DP8	VA	(2)	Residential	3.0		50		30	
EPA land application criteria				380	3300	1600	8600	990	3100

KEY: WP = Wet pond; SM = Shallow marsh; DPSM = Detention basin with shallow marsh; DP = Detention basin; EPA = Maximum metal limits for land application

chromium = nickel = copper > cadmium).

This pattern is nearly identical to their reported concentrations monitored in urban stormwater runoff. It also suggests that rarely monitored (or detected) trace metals, such as chromium, copper, nickel, and possibly cadmium, are actually trapped by stormwater ponds. The muck layers of older ponds often contain more lead than zinc, whereas in younger ponds the converse is true. This may reflect the gradual introduc-

sured by EPA's Toxicity Characteristics Leaching Procedure (TCLP). The TCLP test, or a slight variant, has been applied by four different investigators to pond muck[2, 11, 22, 23] with much the same result—usually less than 5% of the bulk metal concentration is susceptible to leaching.

In general, cadmium and zinc exhibited the greatest potential for leaching (usually less than 10%) while copper and lead showed little or no leaching potential. Moreover, leachate concentrations seldom exceeded the mean metal concentrations reported for urban stormwater runoff.

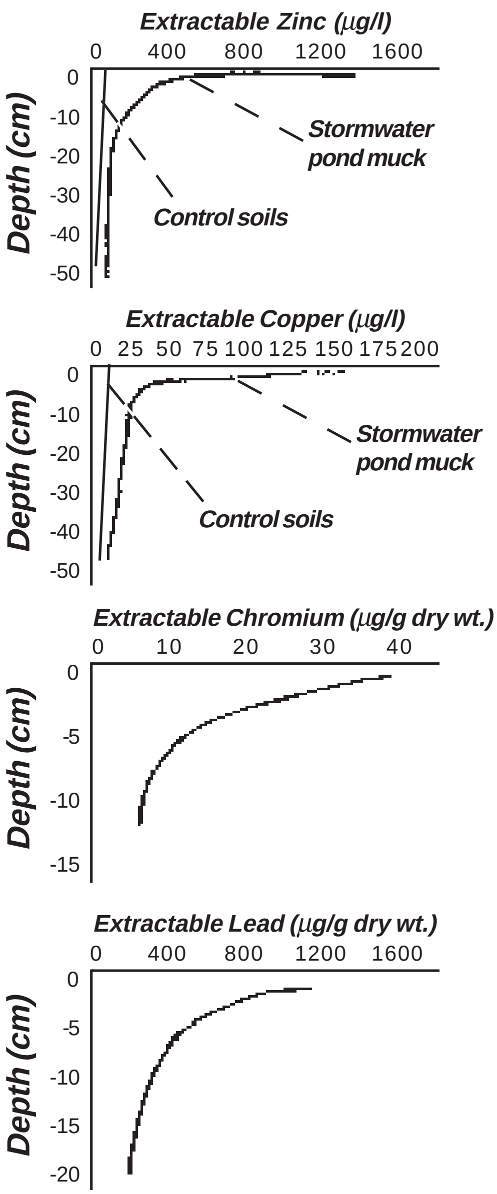
Hydrocarbon Content in Muck

One aspect of the muck layer that has yet to be well explored is the potential for hydrocarbons and PAH contamination. The limited data on hydrocarbon levels in the muck layer (Table 1) are a

Table 3: The effect of land use on trace metal concentrations in the muck layer (mg/kg)

Land Use	No. of Sites	Cadmium	Copper	Lead	Zinc	Nickel	Chromium
Residential	18	2	9.4	44	35	831	
Commercial	5	2	18	214	150	6	22
Road	13	11	30	330	163	52	51
Industrial	2	—	157	489	2135	—	—

Figure 2: Metal profiles with depth *(Adapted from Grizzard, et al., 1983 and Yousef, et al., 1991)*



cause for some concern, particularly at an Auckland, New Zealand industrial site. Gavens[7] reported that the concentration of total PAH and aliphatic hydrocarbons in the muck layer of a 120 year old London basin were 3 and 10 times greater, respectively, than the basal sediments. Only limited biodegradation of the hydrocarbons trapped in the muck appeared to have occurred in the basin in recent years. Yousef[24] on the other hand, reports that hydrocarbons were rarely detected in the muck of Florida ponds.

Aquatic Community

A soupy substrate, high pollutant load, and periodically low oxygen level render the muck layer a rather poor habitat for aquatic life. Macroinvertebrate sampling conducted by Yousef[22] and Galli[5] indicate that the muck layer community has poor diversity and characteristics of high pollution stress. Chironomid and tubificid worms comprised over 90% of all organisms counted in a Florida pond muck layer, and dipteran midge larvae constituted 95% of all organisms collected in the muck layer of a Maryland pond. While the diversity of the community is extremely low, the benthic population can become very dense at certain times of the year. This is not surprising, given that extensive microbe population that uses the highly organic muck layer as an attractive food source.

Comparison of Pond Muck to Sediments Trapped in Other BMPs

How does pond muck compare to the sediments trapped in other best management practices? Table 4 shows that the metal content of the muck layer of wet ponds and stormwater wetlands is quite similar to concentrations seen in the soils of “dry” detention basins. The metal content of pond muck and grassed swale soils are also quite similar in most

Table 4: Comparative metals concentration in BMP sediments (mg/kg) dry weight

BMP	No. of Observations	Cadmium	Copper	Lead	Zinc	Nickel	Chromium
Wet pond	38	6.4	24.5	160	299	38	36
Detention Basin	11	4	59	161	448		30
Grassed swale	8	1.9	27	420	202	13	30
Oil grit separator	13	14	210	320	504		284
Oil grit separator #	4	36	788	1198	6785		350
Sand filter	1	1.3	43	81	182	30	30
Sand filter ##	1	4.6	71	171	418	49	52
Agricultural soils[12]	3000	0.28	30	12	56	24	
Resid. yards[21]	9	0.1	5	13	9		

\# = Oil Grit Separator, serving gas stations ## = Sand filter with sedimentation chamber respects, although swale soils tend to have about twice as much phosphorus and lead as their pond counterparts. Sediments trapped within the filter bed and sedimentation chamber of sand filters also appear to be generally comparable to pond muck, although only one sand filter has been sampled to date.[20]

The one best management practice that sharply departs from this pattern is the oil grit separator (OGS). The metal content of trapped sediment within OGSs is 5 to 20 times higher than other BMPs, particularly if the OGS drains a gas station.[17] Hydrocarbon and priority pollutant levels in OGS sediments are also much higher.

This condition reflects the fact that OGSs often exclusively serve hydrocarbon hotspots and are designed to trap lighter fractions of oil.[18] It is doubtful that metal and hydrocarbon levels in pond muck could approach the level seen in OGSs, since they typically drain larger watersheds that dilute the influence of an individual hydrocarbon hotspot.

Implications for Pond Design and Maintenance

An understanding of the dynamics of the pond muck layer has many implications for the design and maintenance of stormwater ponds.

Pond Clean-out Frequency

Based on observed muck deposition rates, stormwater ponds should require sediment clean-out on a 15 to 25 year cycle.[19, 23] For example, using a 0.5 inch/year muck deposition rate, and assuming that the muck consolidates over time as it deepens, up to 15 to 25% of pond depth can be lost over a 25 year period. The loss of capacity would be faster if construction occurs in the contributing watershed over this time period.

Most ponds are now designed with a forebay to capture sediments. A common forebay sizing criteria is that it constitutes at least 10% of the total pool volume. Based on a 0.5 inch/yr muck deposition rate, and the *untested* assumption that a forebay traps 50% of all muck deposited in the pond, the forebay could lose 25 percent of its capacity within 5 to 7 years. At the same time, the sediment removal frequency for the main pool might be extended to about 50 years. These calculations assume that turbulence in the forebay does not cause muck to be resuspended and exported to the main pool. To meet this critical assumption, the forebay must be reasonably deep (4 to 6 feet) and have exit velocities no greater than 1 foot/second at the maximum design inflow.

The Proper Disposal of Muck

All of the available evidence strongly argues that pond muck does not constitute a hazardous or toxic material. Thus it can be safely land-applied with appropriate techniques to contain any leachate as it dewaters. The high organic matter and nutrient content of pond muck might even make it useful as a soil amendment. Chemical testing of pond muck prior to land application is probably not needed for most residential and commercial sites, given the consistent pattern in the distribution of pond data reviewed in this paper.

Greater care should probably be exercised when disposing of pond muck from industrial sites and perhaps some heavily travelled highways. Although only a few industrial sites have been sampled to date, the data suggests these sites may pose a risk. In addition, there is a much greater chance of pollutant spills, leaks, or illegal discharges occurring in a pond over the 20 or 25 year time span in between clean-outs. It would seem prudent, therefore, to require prior testing at selected industrial and roadway ponds to reduce this risk.

Greater care should probably be exercised when disposing of pond muck from industrial sites and perhaps some heavily travelled highways.

Further Research into the Muck Layer

While our emerging understanding about the muck layer is probably sufficient to make reasonably good management decisions regarding clean-outs and disposal, further research on muck layer dynamics is needed in several areas.

- Ponds need to be sampled to verify the deposition rate of muck over a broader range of geographic and regional conditions. Based on this data a predictive model of muck deposition rates could be developed to help practitioners who design and maintain ponds.

- Much more data needs to be collected concerning the accumulation of hydrocarbons and PAHs in the muck layer, particularly in ponds draining roads and industrial sites. Further testing of the muck layer for these compounds would give managers greater confidence about the proper method for muck disposal, as well as providing inferences about how well stormwater ponds can trap these key pollutants.

- The significance of muck layer phosphorus release as a factor in reducing the long term pollutant removal performance of a stormwater pond remain an open question. Perhaps direct, in-situ measurements of phosphorus flux in a stormwater pond, such as those used for many years in estuarine studies, could help resolve this issue.

- So far, few researches have explored the possible risk of pollutant bio-magnification in the muck layer, either by wetland plant uptake or by bottom feeding fish. A systematic sampling program to define pollutant levels in plant and animal tissue in a large population of stormwater ponds and wetlands would help assess the nature of this risk. Such a survey would also provide helpful guidance to designers on the issue of whether efforts should be made to attract wildlife to these systems.

—TRS

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New approaches to sand filtration designs are rapidly evolving

Developments in Sand Filter Technology to Improve Stormwater Runoff Quality

The use of sand filtration to improve water quality is not a new concept. Slow sand filtra-tion has been used for decades to treat wastewater and purify drinking water in many parts of the globe. In this respect, sand filtration has been demon-strated to be both an economical and effective option for removing pollutants.

The City of Austin, Texas first pioneered the use of sand filters to treat urban stormwater runoff in the early 1980's. The earliest designs consisted of a simple off-line sedimentation chamber and an 18 inch bed of sand (Figure 1). The first flush of runoff is diverted into the first sedimentation chamber. In this chamber coarse sediments drop out and the runoff velocities are reduced. Runoff is then spread over the sand filter bed where pollutants are trapped or strained out. A series of perforated pipes located in a gravel bed collect the runoff passing through the filter bed and subsequently return it into the stream or channel.

This type of sand filter was developed in Austin because no other urban best management practice works well in the Texas hill country. High rates of evapo-transpiration and frequent droughts ruled out the use of ponds and marshes. Thin clay soils and a desire to protect groundwater quality eliminated the use of infiltration practices. Low soil moisture during the hot and dry summers made it difficult to establish dense and vigorous cover needed for vegetative practices. Stormwater designers were thus forced to create a closed and self-contained practice with an artificial filtration media. Hence, the sand filter was developed.

Due to dry conditions in Austin, TX stormwater designers were forced to create a closed and self-contained practice with an artificial filtration media.

Sand filters have many advantages. They have a moderate to high pollutant removal capability, possess very few environmental limitations, require small amounts of land, and can be applied to most development sites, large or small. Compared to most other urban best management practices, they have fewer limitations and constraints. These qualities have made the sand filter an attractive alternative stormwater practice for many

Figure 1: Original sand filter design developed in Austin, Texas ***(Source: City of Austin[3])***

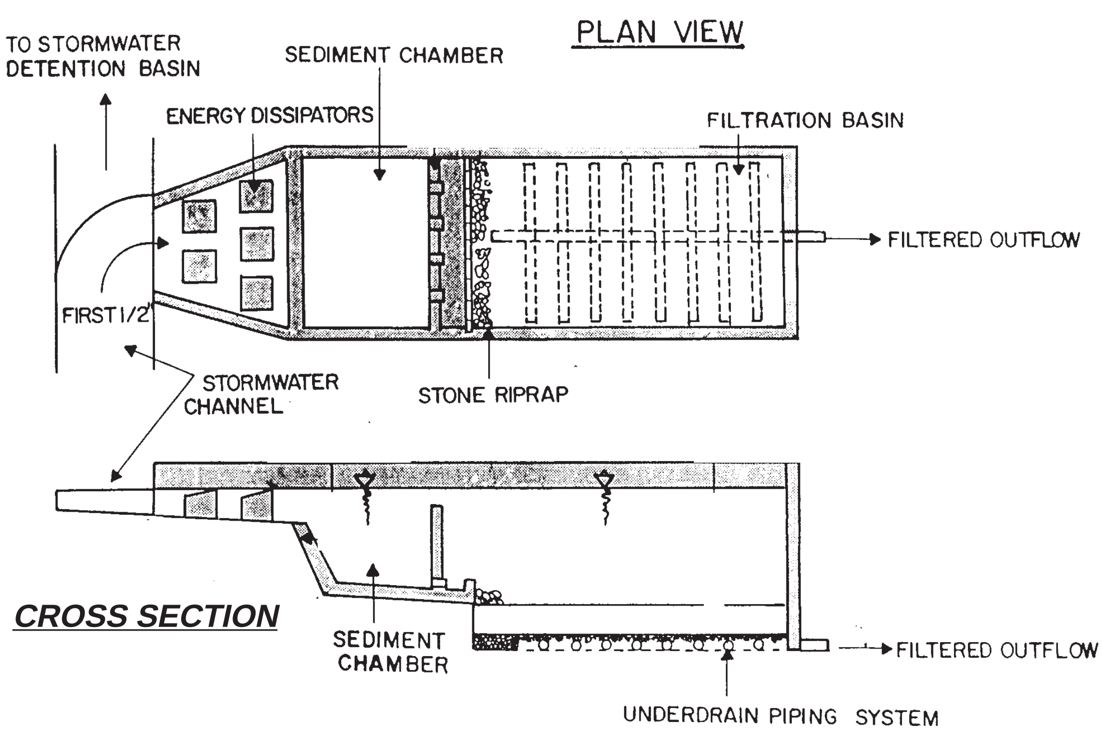

Table 1: Comparison of sand filter design variants

DESIGN VARIABLES	Austin Sand Filter *Full Sedimentation*	Austin Sand Filter *Partial Sedimentation*	District of Columbia Under-ground Sand Filter	Delaware Sand Filter	Alexandria Stone Reservoir Trench	Texas Vertical Sand Filter	Peat Sand Filter	Washington Compost Filter System
Applicable Development Situations and Drainage Area	Most sites can serve 1 to 30 acres		No more than 10 impervious acres of high urban D.A.	No more than 5 acres of impervious parking lot	2 to 3 acres max. of com-mercial or multi-family	Primarily roadway runoff to date	1 to 50 acres	1 to 50 acres
Filter Bed Profile	18" sand, 4-6 inches of gravel. A layer of sod on the surface of the filter bed is optional.		Gravel or Enkadrain screen over 30" of sand	18" of sand	2-4 feet of stone, over 18" of sand and 6" of gravel	Up to 6 feet of sand sup-ported by gabions on either side	Grass on 12" of peat and 2 feet of sand, then gravel	One foot of compost over 8" of rock and gravel
Filter Bed Area (sf/Ia)	100	180	200	360	183	N/A	436	200 ft per cfs
Total Treatment Volume	First 1/2" of runoff with 24 hr. drawdown sediment chamber	First 1/2" of runoff S.C. = 20% of WQV	First flush of runoff (0.3" to 0.5")	First 1" of runoff	First 1/2" of runoff	First 1/2" of runoff	First 1/2" of runoff	N/A
Pretreatment Method	Dry sediment chamber	Dry sediment chamber	3 foot wet micropool plus gravel or geo-textile screen	Shallow wet pool	Wet micropool stone blanket	Dry sediment chamber	Wet micropool	Dry sediment chamber
Pretreatment Volume	sc >> fb	sc ~= fb	sc >> fb	sc = fb	sc < fb	sc >> fb	0.1 acre-inch sc < fb	sc < fb
Performance Monitoring Data Available?	Yes, 4 sites with 2 more in progress		No, 2 in progress	No, 2 in progress	No	No, 1 in progress	No	Yes, 2
No. Currently Installed	~500	~500	~50	~25	~10	~5	~5	25
Design Reference	3	3	12	10	2	N/A	2 and 6	11

Notes: ***sf/Ia = square foot of filter bed area per impervious acre***

sc = sedimentation chamber   fb = filter bed

— Table 1 continues on page 50 —

Figure 2: Cross-section of sand filter design variations

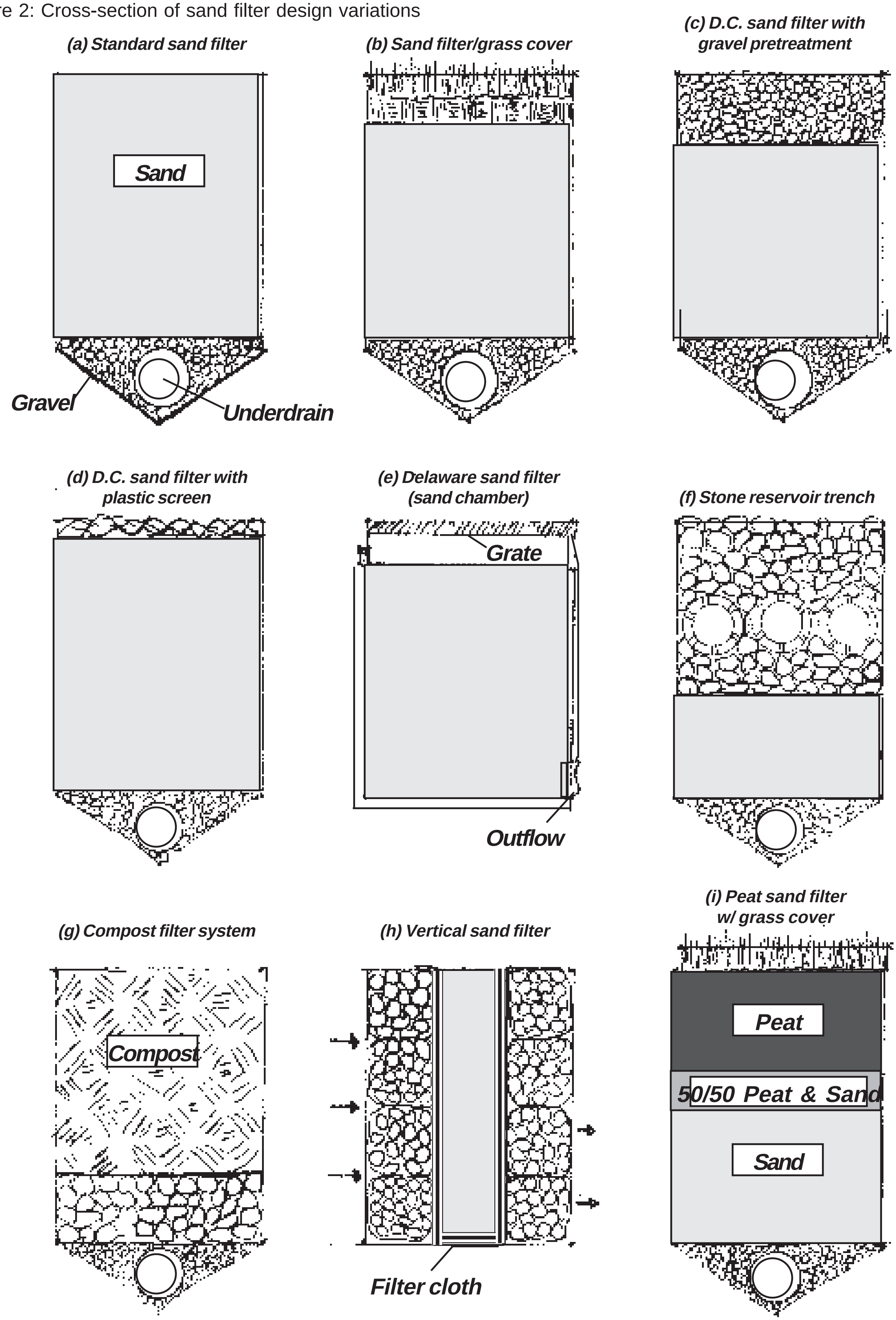

Table 1 (con't.): Comparison of sand filter design variants

Filter Type	Design Issues
Austin Sand Filter *Full Sedimentation*	Requires basin liner, 2:1 length to width ratio. Sand must have a grain size ≤ concrete sand.
Austin Sand Filter *Partial Sedimentation*	Requires more frequent sand replacement than full sedimentation design. Requires basin liner.
District of Columbia Underground Sand Filter	Need head-room, must avoid underground utilities. Must ensure each chamber is watertight, may require 4 - 8 ft. of head.
Delaware Sand Filter	Requires very little head. Grate covers each chamber for access. Need to consider structural design with traffic load. Can freeze in northern climates.
Alexandria Stone Reservoir Trench	Not recommended for parking lots.
Texas Vertical Sand Filter	Most filtration may occur in small area of filter. Ability to withstand clogging has not been demonstrated.
Peat Sand Filter	Need to select appropriate peat. Peat may not always be available. Difficulty in operating during winter conditions.
Washington Compost Filter System	Leaf compost must be carefully selected and replaced regularly.

communities across the country.

This article examines recent developments in the use of sand filtration to improve the quality of urban stormwater runoff. It summarizes what is known about the performance and operation of sand filters, based both on recent research and the experience of engineers and public works officials that have installed and maintained them.

At least seven performance monitoring studies are in progress in Texas, Delaware, Florida, Virginia, the District of Columbia, and Washington.

Design Variations of the Sand Filter

The versatility of the sand filter is reflected in the numerous design variations that have been developed to address many different climatic and development conditions. Nearly a dozen variants of the basic sand filter design are currently in use, and engineers and practitioners continue to create more. Some of the more common designs are compared in Table 1, and illustrated in Figure 2.

In general, sand filter designs can be grouped into two broad categories:

- designs that are well established; and
- those that are still somewhat experimental (due to a lack of implementation experience and/or performance monitoring data).

Each sand filter design utilizes a slightly different profile within the filter bed (Figure 2). The required surface area of the filter is usually a direct function of the impervious acreage treated, and varies regionally due to rainfall patterns and local criteria for the volume needed for water quality treatment. In addition, designs often differ with respect to the type and volume of pretreatment afforded.

The most common form of pretreatment is a wet or dry sedimentation chamber. Gravel or geotextile screens are sometimes used as a secondary form of protection. The relative volume dedicated to pretreatment versus filtration tends to vary considerably from one area to the next (Table 1). Nearly all sand filters are constructed off-line. Runoff volumes in excess of the water quality treatment volume must be bypassed to a downstream quantity control structure.

Feasibility of Sand Filters

Some kind of sand filter can be applied to almost any development site. The primary physical requirement is a minimum of 2 or 3 feet of head differential existing between the inlet and outlet of the filter bed. This is needed to provide gravity flow through the bed.

Otherwise, use of sand filters is only limited by their cost and local maintenance capability. Sand filters are particularly suitable for smaller development sites where other stormwater practices are often not practical. These include the following:

- Infill developments;
- Ultra-urban downtown areas ;
- Gas stations and fast food establishments;
- Commercial and institutional parking lots;
- Small shopping centers;
- Townhouse and multifamily developments; and
- Confined industrial areas

Care should be exercised in approving sand filters for individual lots and residential developments, as most homeowners lack the incentives or resources to regularly perform needed sand replacement operations. The State of Florida is considering limitations on the use of sand filters in residential areas, given the generally poor maintenance record of homeowner associations.[8]

Pollutant Removal Performance of Sand Filters

Presently, performance monitoring data for sand filters is rather sparse. Frequently cited are results from four sand filters that were sampled in Austin, Texas in the late 1980's (Table 2). However, at least seven additional performance monitoring studies are now in progress in Texas, Delaware, Florida, Virginia, the District of Columbia, and

Washington with results expected in the next 6 to 18 months.

Initial monitoring results suggest that sand filters are very effective in removing particulate pollutants such as total suspended solids, lead, zinc, organic carbon, and organic nitrogen.[4] Removal rates in excess of 75% were frequently observed for each of these parameters. Removal rates for coliform bacteria, ammonia, ortho phosphorus, and copper were moderate, and quite variable. Results ranged from 20 to 75% in the four sand filters tested in Austin.

Negative removal rates were frequently reported for total dissolved solids (TDS) and nitrate-nitrogen. The negative TDS rate may be due to the preferential leaching of cations from organic matter trapped on the surface of sand filter. Similarly, the nitrate export observed in three of the four sand filters may indicate that nitrification is taking place in the filter bed. In the nitrification process, microbial bacteria converts ammonia-nitrogen into the nitrate form of nitrogen. The apparent loss of ammonia through the filter bed, coupled with the production of excess nitrate, strongly suggests that nitrification is taking place.

The pollutant removal behavior of stormwater sand filters is quite comparable to that reported for sand filters used in wastewater treatment.[5] There are some differences between the two systems, however. Wastewater sand filters typically contain finer sand, are cleaned more frequently, and subject to more uniform and controlled flow than their stormwater counterparts. Consequently, wastewater filters exhibit slightly higher removal rates for sediment, phosphorus, and organic carbon (often in excess of 90%), but seldom can achieve more than 20% removal of nitrate (again, due to nitrification).

The one exception where wastewater filter consistently outperformed stormwater filters was bacteria removal. Wastewater filters frequently reduced bacteria levels by 90%, compared to a 25 to 65% removal for stormwater sand filters.

Table 2: Pollutant Removal Performance of Four Sand Filters in Austin, TX — Pollutant removal accounts for bypassed flows ***(adapted from Austin ERMD, 1990)***

Parameter	Highwood	Barton Creek	Joleyville	Brodie Oaks
Total solids	86	75	87	92
Total dissolved solids	(-35)	1	31	46
BOD (5-day)	29	39	52	77
Total organic carbon	53	49	62	93
Nitrate	(-5)	(-13)	(-79)	23
Ammonia	59	43	77	94
Total Kjeldahl nitrogen	48	64	62	90
Total nitrogen	31	44	32	71
Total phosphorus	19	59	61	80
Fecal coliforms	37	36	37	83
Fecal strep	50	25	65	81
Copper	33	34	60	84
Lead	71	88	81	89
Zinc	49	82	80	91
Iron	63	67	86	84

Prospects for Improving the Performance of Stormwater Filters

Designers are constantly refining the basic sand filter design to increase the level and consistency of nutrient and bacteria removal. A popular approach has been to add an additional organic layer to the filter bed to increase pollutant removal capability. A series of organic media have been used including a top layer of grass/soil, grass/peat or compost, a middle layer of peat, activated carbon, and even zeolites.

Very few of these "sandwich systems" have been extensively monitored so far. The Highwood sand filter (see Figure 2) had a top layer of grass sod over the sand filter, and generally performed slightly worse than the other three Austin filter systems.[4] The stormwater compost system which relies exclusively on an organic filtering medium (Described in Technical Note 3) also had negative or low removal of TDS, nitrate, and phosphorus.[11] The limited data on sandwich systems so far indicates that the sandwich layer could actually be a source for some pollutants, while effectively trapping others.

Another option to improve sand filter performance is to create a permanently saturated, anaerobic zone at the bottom of the filter bed. Conditions in this zone are favorable for denitrification, which might substantially improve the rate of nitrate removal. Some caution may be in order as anaerobic conditions could possibly lead to loss of other pollutants.[7] Other untested methods for enhancing performance may include increasing the surface area of the filter bed, specifying the use of finer sand, and increasing the depth of the sand layer.

It should be noted that sand filters, as an off-line practice, will always bypass some fraction of runoff during larger storm events. This runoff will be untreated. Depending on local water quality sizing criteria, the volume of untreated runoff can amount to 10 to 20% of the annual runoff volume produced at the site.

Perhaps the most reliable option for improving sand filter performance is to combine a filter with another BMP such as an extended detention pond, wet pond, or shallow marsh. For example, the best performing sand filter in Austin monitoring project was at Brodie Oaks, which combined a retention pond with a sand filter (See Table 2).

Sand Filter Maintenance

Regular maintenance is an essential component of the operation of a sand filter. At least once a year each filter should be inspected after a storm to assess the filtration capacity of the filter bed. Most filters exhibit diminished capacity after a few years due to surface clogging by organic matter, fine silts, hydrocarbons, and algal matter. Maintenance operations to restore the filtration capacity are relatively simple—manual removal of the top few inches of discolored sand followed by replacement with fresh sand. The contaminated sand is then dewatered and land-filled.

Operation of the sand filter requires replacement of the surface sand layer on a relatively frequent basis — just as in wastewater filter applications.

The key point is that the operation of the sand filter requires replacement of the surface sand layer on a relatively frequent basis — just as in wastewater sand filter applications. If periodic sand replacement is not conducted, the filter will not be effective. Livingston[8] reports chronic clogging problems in many of the sand filters installed in residential areas in Florida due to lack of maintenance and off-site sediment deposition.

In some cases sand filters can continue to function after partial clogging. For example, Shaver and Baldwin[10] reported that a demonstration sand filter accumulated several inches of deposits over the sand filter bed after six years, but it still functioned, at least partially. Based on the one sample obtained from a Delaware site, sand filter deposits appear to have the same degree of sediment contamination as pond muck and thus may not pose a risk for land disposal.[10] (See page 10 of this issue for a discussion of pond muck disposal.) This conclusion, however, should be considered provisional until further testing of more filter sediments are obtained from sites that are heavily influenced by automotive or industrial uses.

A number of techniques are being developed to reduce the frequency of sand replacement or to make the operation more convenient.

- **Surface Screen.** Underground sand filters in heavily urbanized areas tend to receive large quantities of trash, litter, and organic detritus. To combat this problem, the District of Columbia specifies the use of a wide mesh geotextile screen (EnkaDrain 9120) on the surface of the filter bed to trap these materials. During maintenance operations the screen is rolled up, removed, cleaned, and reinstalled.

- **Careful Selection of Sod.** Some sand filters that are constructed with a grass cover crop have lost significant filtration capability soon after construction. The clogging is often traced to sod that has an unusually high fraction of fine silts and clays. In other situations, grass roots grow into the sand layer and improve the filtration rate.

- **Limiting Use of Filter Fabric to Separate Layers.** Often the loss of filtration capacity occurs where filter fabric is used to separate different layers or media within the filter bed, such as in "sandwich" filters. As a general rule, the less use of filter fabric to separate layers, the better. In many situations, layers of different media can be intergraded together at the boundary (e.g., 50:50 peat/sand), or by a shallow layer of pea gravel.

- **Providing easier access.** During sand replacement operations, heavy and often wet sand must be manually removed from the filter bed. It is surprising that so few designs help a maintenance worker conveniently perform this operation. It is not uncommon that sand must be lifted 6 feet or higher to get it out of the filter bed. Yet typically no ramps, manhole steps, or ringbolts are provided to make the operation easier.

  Engineers should also keep in mind the ergonomics of maintenance when designing access to the sand filter. In some cases, heavy grates or large diameter manhole covers are specified that cannot be opened without the use of a portable winch.

- **Pretreatment**. The frequency of sand replacement can also be reduced by devoting a greater volume to runoff pretreatment in the sedimentation chamber. Several designs provide up to 50% of the total runoff treatment volume in the sedimentation chamber.

- **Visibility and Simplicity.** When tinkering with new sand filter designs, two key principles should be kept in mind. First, the filter should be visible, i.e., that it be easily recognized as a BMP (so that

Table 3: Construction costs for various types of sand filters

Region (Design)	Cost/Imperv. Acre
Delaware	$10,000
Alexandria (Del.)	$23,500
Austin (>2 acres)	$16,000
Austin (>5 acres)	$ 3,400
DC (underground)	$14,000
Denver[14]	$30 - $50,000
OIL-GRIT SEPARATOR	$ 8,000
INFILTRATION TRENCH[16]	$ 800-1200
PONDS[16]	$ 400-1200

owners realize what it is) and can be quickly located (so that it can be routinely inspected). This often requires the designer to consider the appearance and aesthetics of the final product so that it does not come to resemble a concrete sandbox. The second principle is that the design should be kept as simple as possible. Experience has shown that overly complex designs create greater operation and maintenance costs.

- **Imperviousness.** Limit sand filters only to sites that are entirely impervious.

Economics of Sand Filters

Constructing sand filters can be expensive (Table 3). Construction costs often range from $10,000 to $20,000 per impervious acre treated, depending on the design. Sand filters can cost as much as 5 to 10 times more per unit of runoff treated than conventional BMPs, exclusive of land costs.

It should be noted, however, that many sand filters require little or no developable land (since they are located underground or on the margin of parking lots), which can make filters a more competitive option. The drawback is that sand filter do not provide stormwater quantity control. Thus, savings in land consumption may be offset by the costs of constructing additional stormwater quantity controls elsewhere on the site.

In many small, highly urbanized development situations sand filters are often the only practical stormwater quality practice, making cost comparisons meaningless. Indeed, the relatively high treatment cost for sand filters may prove useful as a benchmark to set and justify waiver fees for small development sites, when no urban BMP options are practical.

Economies of scale do exist for sand filters. It is, for example, much cheaper to build a filter serving a large drainage area than a small area. Tull[13] reports construction costs of $16,000/acre for a filter on one acre compared to $2,700/acre for one built on 20 acres. In addition, construction costs for sand filters can be expected to drop over time. These savings reflect greater use of precast or modular components, better construction specifications, and greater experience on the part of contractors. For example, Bell and Nguyen[1] report a drop of nearly 50% in the cost of constructing underground sand filters over a five year period.

Not much is known about the cost to maintain sand filter over the long term, or, for that matter, the cost of sand replacement operations. Given the importance of maintenance, the collection of such information should be a key priority.

Regional Design Considerations

Communities that are considering sand filters in their arsenal of watershed protection techniques should keep in mind several regional design issues.

- Sand filters have yet to be widely applied in colder northern climates. Clearly, an extended cold snap could freeze the sedimentation chamber and perhaps even the surface of the filter bed (particularly for designs with relatively shallow chambers). If this happens, the filter may be temporarily rendered partially or entirely ineffective. It is therefore quite prudent to design a bypass that will route excess runoff directly into the storm drain system or stream channel under these conditions. A few designs, such as the peat sand filter, are not designed to operate in the winter months.
- The delta-T of sand filters has yet to be measured to determine if they contribute to warming of sensitive cool or cold-water streams. On one hand, sand filters might cool incoming runoff since it must pass through the sand and gravel layers of the filter bed. On the other hand, cooling may be more than offset by warming in the sedimentation pool or from concrete surfaces.
- Sand filters need not always be lined by concrete to work effectively. In regions where groundwater quality is not a critical concern (e.g., communities that allow or encourage the infiltration of stormwater), the bottom and sides of the filter bed can be contained by geotextile or even soil liners. The filter bed is excavated, permeable filter fabric used to line the bottom and sides of the structure, and then sand added.

Sand filters can cost as much as 5 to 10 times more per unit runoff treated than conventional BMPs, exclusive of land costs.

Further Research and Development

Sand filters are a very promising and potentially useful stormwater practice. Yet, much more still needs to be learned before they can be routinely and cost-effectively applied in many regions of the country. Questions include the following.

- How well does the design filtration rate hold up over time? — Does it vary from season to season due to leaf fall or frozen conditions? — Does the filtration rate recover as organic surface deposits gradually decompose?

  Research into these questions will help to define "run-time" of a filter (i.e., how often sand must be replaced). To optimize removal, engineers have found it necessary to accurately predict how long wastewater filters will run before they must be backflushed or replaced. The same kind of operational data will ultimately be needed for stormwater filters.

- Can the efficiency of pretreatment be improved? Would a gravel filled sedimentation chamber be more effective than an empty one?

  Some researchers have concluded that gravel filters are superior to conventional sedimentation basins for pretreatment in wastewater sand filters.[5,15] So far, this approach has not been used for stormwater sand filters, possibly because of the difficulties in cleaning a gravel chamber.

- Should additional media be added to sand filters to increase their nutrient removal capability?

Ultimately, the growth in the application of sand filters will be constrained by cost and maintenance factors.

Clearly, there are some risks that these additional layers of organic material could reduce the run time of the filter, or even possibly be a source of pollutant leaching. Some researchers are even testing inorganics including ferric chloride and aluminium sulfate precipitates. Only through controlled laboratory column experiments with various combinations of filter media can these questions be answered.

In addition to the above, there are several interesting questions about sand filters that remain. Do sand filters contribute to downstream warming? Are accumulated deposits on the filter bed toxic or hazardous when the filter serves a highly automotive or industrial site? Are there better combinations of sand grain size or filter bed depth that might improve the effectiveness of a sand filter? What is the optimal type and volume of pretreatment? What design refinements can reduce construction or maintenance costs?

An Overall Assessment

The design of sand filters is evolving rapidly, and promises to remain a fertile ground for innovation for years to come. Some experimental approaches will prove successful, while others will doubtless be discarded. The arrival of additional performance monitoring information over the next two years should help to define, and hopefully standardize, the most effective design concepts.

Ultimately, however, the growth in the application of sand filters will be constrained by cost and maintenance factors. Continued effort is needed to monitor the operation of sand filters. Such data could yield reductions in the costs of constructing and maintaining filters. If such cost reductions can be realized, sand filters will become an attractive option over a much wider range of development conditions.

—TRS

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Pollutants leached from snow packs can dramatically impact water quality

Influence of Snowmelt Dynamics on Stormwater Runoff Quality

By: Gary L. Oberts, Metropolitan Council, St. Paul, MN

Potential water pollution problems associated with melting snow are a concern to watershed managers in northern climates. In fact, in some urban areas substantial portions of the annual load of pollutants such as hydrocarbons, metals, solids, nutrients, and chlorides come from snowmelt and early spring runoff events. Thus the annual cycle of pollutant build-up and subsequent release during snowmelt can be a real threat to the attainment of water quality objectives.

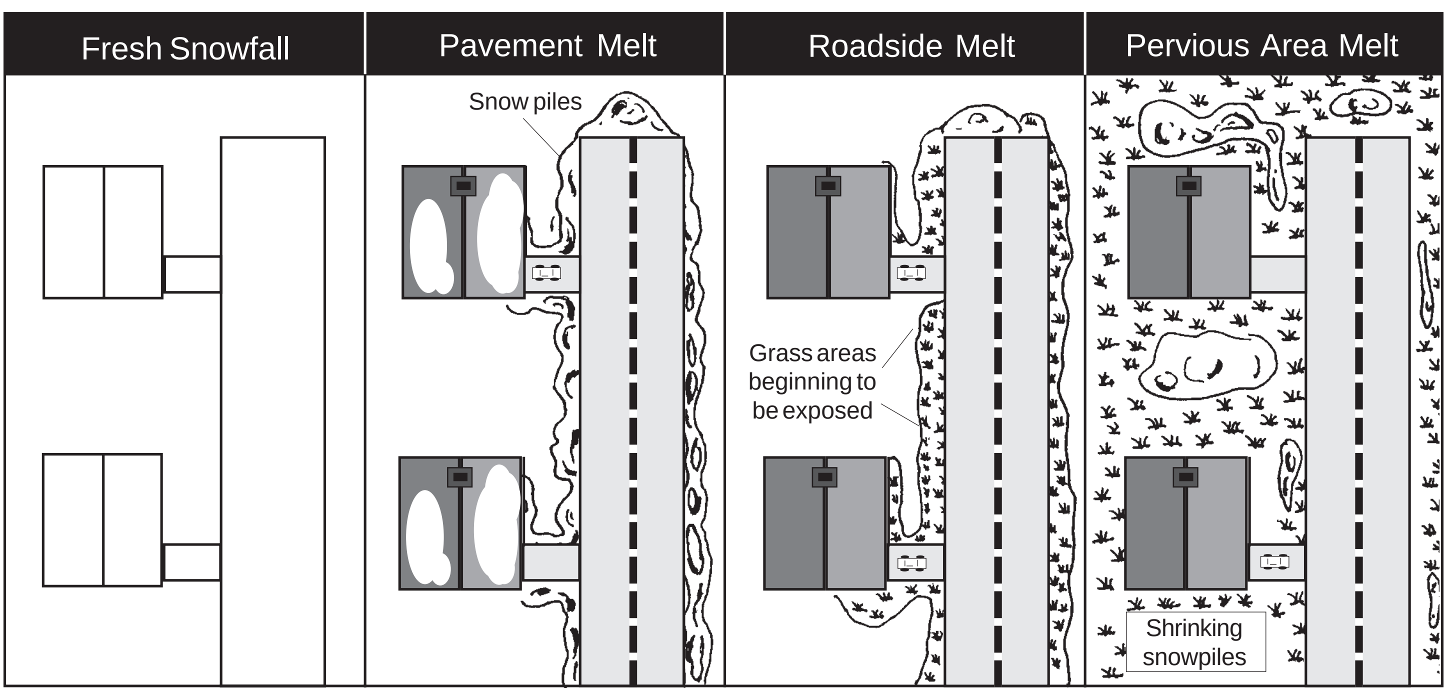
This article examines the mechanisms involved in snow pollutant accumulation and the movement of various pollutants from the snowpack. With this knowledge practitioners can plan management actions to anticipate changing flows and pollutant concentrations. Techniques that can be incorporated include the designation of "salt-free" areas near key streams and wetlands, and dumping plowed snow in pervious areas where melt water can infiltrate.

The Snowmelt Sequence

Snowmelt can be described as a predictable process with three distinct stages (Figure 1). The first stage is called *pavement melt*. As the name implies, it occurs when deicers are applied and/or solar radiation takes effect on heat-absorbing paved areas. These applications result in a winter-long sequence of chemi-cally-driven melt events in which very saline water carries accumulated road surface material into drainage systems and local receiving waters.

The second stage involves the more gradual melt of snow piles adjacent to road surfaces. *Roadside melt* contributes runoff intermittently as chemical splash and solar radiation gradually reduce piled snow. The final stage of the snowmelt sequence is the melt of non-paved pervious areas of the site, such as grassed lawns. The *pervious area*

Figure 1: Representation of the snowmelt sequence



melt stage has the potential to contribute a substantial volume of runoff quickly, particularly when accelerated by a rain event.

Runoff Quantity

The volume of runoff generated by each of the three melt stages is dictated primarily by the amount of snow and the weather conditions (Table 1). In most cases, runoff produced during pavement melt is not substantial. The end-of-season melt of the snowpack (i.e., roadside and pervious area melt), however, often constitutes one of the largest single annual runoff events in northern climates. Often this melt lasts several weeks and can be magnified with concurrent rainfall.[2, 10, 32]

High levels of chloride, lead, iron, phosphorus, BOD and total suspended solids have been reported

Figure 2 is an example of the significance of the large runoff produced by an end-of-season snowmelt event in an urban catchment in Minnesota.[22] The importance of the melt event was magnified by several rain-on-snow events (total of 0.77 inches) that occurred from mid-March to early-April, 1989. The snowmelt runoff is dramatic relative to the annual water budget, particularly when compared with the larger rain events (e.g., a 3.41 inch storm — 10 year frequency — that occurred in May, 1988).

Runoff Quality

Pollutant Sources

Pollutants accumulate in snow due to several processes. First, falling snowflakes are effective scavengers of both particulate and aerosol pollutants.[7] After snow has fallen, the snowpack is subject to both episodic and continual deposition of airborne pollutants from local urban activities, as well as long distance transport of pollutants from activities unrelated to the locale.[8, 15, 25, 31, 33] Atmospheric contributions of toxic chemicals, nutrients, and solids have been noted as a particularly prevalent pollutants on urban surfaces throughout the winter from sources such as fossil fuel combustion, refuse incineration, chemical processing, metal plating, and manufacturing.[4, 12, 16, 18, 26]

Pollutants are also directly deposited on the snowpack and other cleared surfaces in winter. Most of the street surface studies, however, have not focused on the build-up of pollutants under snowy conditions. This omission is critical because street loads of sediment and toxic materials are at an annual peak at the onset of winter melt and early spring rainfalls.[2] Vehicular deposition of petroleum products/additives and metals, the direct application of salt and anti-skid grits, and roadway deterioration are major contributors to the pollution of road surface snow.[16, 20, 28]

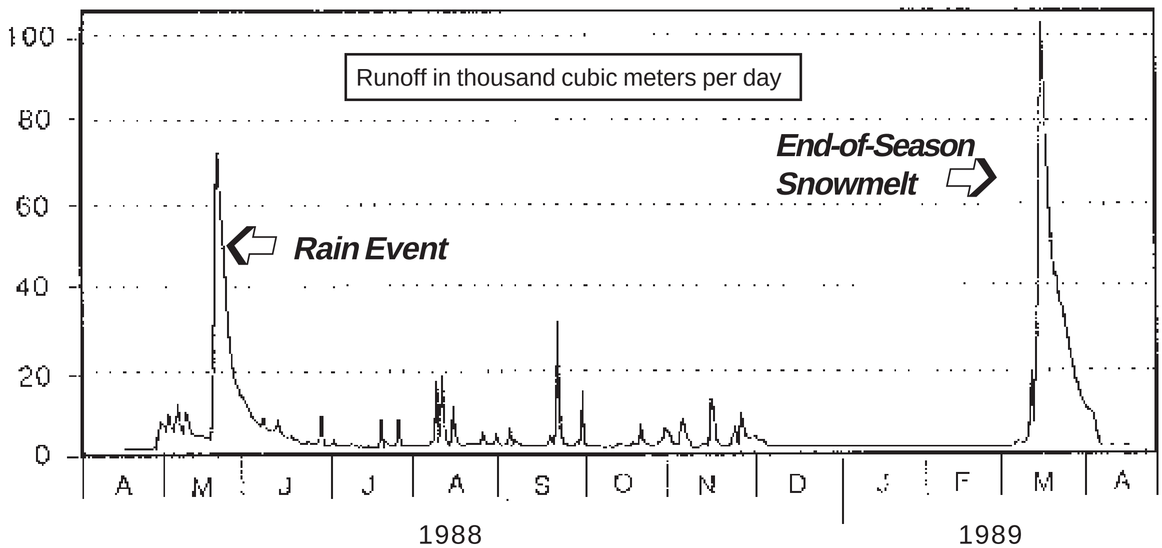
"First Melt" Effect

Roadway snow is quickly removed by rapid melt through salt application, removal to a dump site, or plowing over the roadway curb/edge. The first action results in immediate runoff, usually involving small volumes of water and a minor portion of the annual pollution load, although concentrations may be high.[17] For example, in 1980 small mid-winter melts in Minnesota accounted for less than 5% of the annual total phosphorous (TP) and total lead (TPb) loads, respectively. In contrast the end-of-winter melt accounted for about 8 to 20% of the TP and TPb annual loads.[19]

Table 1: Runoff and pollutant characteristics of snowmelt stages

Snowmelt Stage	Duration/ Frequency	Runoff Volume	Pollutant Characteristics
1. Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluable pollutants, Cl^-, nitrate, lead. Total load is minimal.
2. Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluable and particulate pollutants
3. Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-snow Melt	Short	Extreme	High concentration of particulate pollutants, moderate to high concentrations of soluable pollutants. High total load.

Figure 2: Runoff hydrograph of an urban basin in St. Paul, MN



Runoff pollution from snow removed to a dump site is a topic that has been well studied, particularly in Canada. High levels of chloride, lead, iron, phosphorus, biochemical oxygen demand, and total suspended solids have been reported in snow dump runoff.[14, 23, 24, 27, 30]

Roadside Snowpack

Plowing snow over to the roadside edge allows for the accumulation of debris, chemicals, grit, and litter over an entire winter. This material is easily mobilized in either short, chemically-driven melts or the larger end-of-season event. Material may also remain available for early spring rainfall washoff. Levels of contamination in a roadside snowpack can reach or even exceed that in the snowpack at a dump site.[23, 24, 27, 30]

Once pollutants collect in a snowpack, a process of pollutant speciation associated with the freeze/thaw cycle begins to develop. This process has been called several different terms, including “freeze exclusion,” “preferential elution,” and “acid flushing.” All these titles refer to basically the same phenomenon wherein soluble pollutants are flushed from throughout the snowpack and concentrate at the bottom of the pack.

Several authors describe a process that begins when snowflakes respond to freezing and thawing cycles by metamorphosing (when ice crystals enlarge and round).[7, 11, 25] The reforming crystalline lattice does not allow impurities to be incorporated, so the impurities migrate to the outside of the crystal. They are loosely bound in this position and thus exposed for washoff by passing meltwater.

The heterogeneous nature of the snowpack allows for channelized meltwater to scavenge soluble pollutants randomly until the pack is saturated, whereupon pollutant mobilization becomes more uniform throughout the pack. In this condition, soluble pollutants are collected in a “wetted front” that moves through the pack, eventually reaching the bottom. At this position they intersect the soil or other surface and move from the pack as a highly concentrated, usually acidic, pulse of meltwater. This “first flush” of concentrated snowpack meltwater will either infiltrate into the soil or runoff, depending upon the conditions of the surface soils underlying the snowpack.

A majority of the pollutants are washed out at the beginning of snowmelt runoff.

The degree to which soluble pollutants are washed from the snowpack depends upon the number of freeze/thaw cycles during the winter and whether the pack receives any outside moisture. Repeated freezing and thawing “purify” the hexagonal crystals and any added moisture mobilizes the released pollutants more quickly. Johannessen and Henriksen[13] found in both laboratory and field studies that about 40 to 80% of 16 pollutants were released from experimental snowpacks with the first 30% of the liquid melt. This process seemed to be independent of the initial snowpack concentration of the pollutants. Their studies also showed that pollutant concentrations in the initial melt were 2 to 2.5 times greater than those in the remaining snowpack (reaching as high as 6.5 times the snowpack levels in the very first fractions of melt.

Zapf-Gilje, *et al.*[34] found in their study of frozen secondary effluent that the first 20% of a melt contained 65% of the phosphorus and 90% of the total nitrogen. The removal was not related to initial pollutant content in the frozen effluent. In contrast, Schondorf and Herrmann[25] reported that 90% of the particulate-associated polycyclic aromatic hydrocarbons (PAHs) in a snow column were contributed in the last 10% of the melt.

Particulate matter is filtered or coagulated with other particles as it moves through the snowpack and remains behind while the soluble component washes through. Pollutants such as tightly bound organics and metals adsorb to sediment and organic compounds. Schondorf and Herrmann[25] also found that rain-on-snow washes fine-grained particulate through the pack and flushes out metals and adsorbed organic pollutants.

Extreme pollutant loads can be experienced during the end-of-the-season melt if rain

Infiltration

Infiltration can occur at the bottom of a snowpack even into frozen or partially frozen soils. In fact, the very first portions of a melt generally infiltrate until the soil becomes saturated, leading to a progressive reduction in infiltration capacity.[3] Novotny[17] explains that infiltration of substantial volumes of meltwater can occur into clay and loam soils, as well as sands, if impermeable frozen layers do not form before snow cover. The formation of these “concrete frosts” is a function of the amount of pore-water of the soil.[3]

Less soil moisture at freeze-up allows more meltwater to move through the available pore spaces. Once soils are saturated, however, the amount of runoff from the soil surface becomes a function of the degree of melt and the amount of downward movement of water through saturated soils. This situation can make the entire catchment 100% “functionally impervious” with the catchment actually contributing meltwater runoff. Bengtsson[3] and Colbeck[6,7] demonstrated that infiltration can vary from 0-100%, depending upon the nature of the soil, the water content of the soil at freeze-up, and the degree of saturation reached during a melt event.

Runoff

The net effect of freeze exclusion is that meltwater moving from a snowpack has a different chemical quality depending upon the stage of the melt. Early in the melt, the primary movement out of the pack will be from soluble pollutants, followed by the particulate fraction. This applies only to water as it moves from the snowpack, however. It should be noted that the large volume of meltwater leaving the pack, particularly at peak melt, also can wash off accumulated pollutants from paved surfaces as well as picking up additional pollutants from saturated soil surfaces.

Because the initial stages of melt are generally slow, the first melt stage runoff exerts a concentration “shock” of highly soluble pollutants, but not a high pollution load. More runoff is produced in the latter stages of the melt, which can generate high concentrations and high loads because particulates are washed out of the pack.

Rain-on-snow

Extreme pollutant loads can be experienced during the end-of-the-season melt if rain falls on a deep, saturated snowpack that has undergone repeated freeze-thaw cycles.[8, 25] This event leads to a

Table 2: Flow-weighted mean snowmelt concentrations in St. Paul area by site type compared with national NURP study averages. Data reported in mg/l. (N)=No. of events.

	Total susp. solids	Volatile susp. solids	Chemical oxygen demand	Total phos.	Dissolved phos.	Total Kjeldahl nitrogen	Nitrate	Cloride	Total lead
Storm Sewers (20-40)	148	46	169	0.70	0.25	3.52	1.04	230	0.16
Open Channels (1-5)	88	15	82	0.56	0.18	2.36	0.89	49	0.2
Creeks (2)	64	–	84	0.54	–	3.99	0.65	116	0.08
MEDIAN	112	38	112	0.70	0.18	3.39	0.91	116	0.10
NURP*	–	–	91	0.46	0.16	2.35	0.96	–	0.18

*Runoff concentrations were obtained from over 2,300 rainfall events monitored at 22 project sites across the nation sudden release of soluble pollutants from the wetted front at the same time that soluble and particulate pollutants are flushed from the snowpack by the rainfall.

The large volume of melt runoff associated with rain-on-snow events also flushes pollutants that have accumulated on paved and soil surfaces. The intensity of a rain-on-snow event is usually greater than a summer thunderstorm because the soil is saturated or frozen and the rapidly melting snowpack provides added runoff volume.

Levels of Pollution

Monitoring of pollutant concentrations in snowmelt runoff is much more scarce than monitoring of rainfall runoff events. Research in the Minneapolis-St. Paul region of Minnesota over the last decade has shed more light on pollutant concentrations in snowmelt. Runoff data from 49 short-term January and February snowmelts and end-of-season March and April snowmelt events are provided in Table 2.[19, 21, 22] For comparison, the table also lists national runoff concentrations obtained from NURP sites.[29] Snowmelt runoff contains elevated levels of solids, nutrient, and chemical oxygen demand (COD), in addition to the high levels of lead and chloride. Both total and volatile suspended solids concentrations in snowmelt runoff are considerably lower than the flow-weighted mean concentrations from rainfall events collected at the same sites. Concentrations of COD, organic nitrogen (TKN), and lead are higher in the melt events for most sites, and chloride and nitrate are much higher in the melt at all sites. Total and dissolved phosphorous are generally similar for both snowmelt and rainfall runoff.

A review of monitoring data from other locations shows that the Minnesota values are within the range of snowmelt runoff quality observed elsewhere. Snowmelt runoff measured in Ottawa revealed that even though high concentrations of lead and chloride accumulate in snow dumps and along roadsides, the actual levels in runoff are much lower.[14, 23] This is thought to be due to infiltration and adsorption of pollutants to soils during melt. For example, lead concentrations in Ottawa roadside and snow dumps reached levels as high as 113 mg/l, but concentrations from this snow after it had melted declined to <0.01 to 1.19 mg/l.

Sediment samples taken from a river near the dump sites showed lead levels as high as 1,344 mg/kg, but dropped to 183 mg/kg the year after dumping stopped near the site. Chlorides from this same study in Ottawa reached as high as 15,266 mg/l in a snowpack adjacent to a street in a commercial area and 2,500 mg/l at the dumps, but runoff levels from a storm sewer in the city declined to 219 mg/l (again close to the Table 2 values for runoff) and the dump averaged 500 mg/l.

Soderlund, *et al.*[28] reported snowmelt runoff in Stockholm reached levels as high as 450 mg/l chloride, 12 mg/l oil, and 1.0 mg/l total phosphorus. The authors found that rapidly rising temperatures generated a substantial volume of meltwater, which then washed a tremendous amount of accumulated winter debris from street surfaces. Again, monitoring the rain events during or shortly after the melt of the snowpack yielded very high concentrations of many pollutants.

Pierstorff and Bishop[24] reported that dump site melt runoff from Durham, New Hampshire and elsewhere reached as high as 664 mg/l Cl, 50 mg/l COD, and 13 mg/l oil and grease. Boom and Marsalek[4] found that PAH levels in Sault Ste. Marie, Ontario, meltwater runoff (3 to 12 μg/l) differed little from the levels seen in the snowpack. Couillard[8] noted that melt events exhibited very toxic levels of metals and that rain occurring during a melt tended to dilute the concentration, and hence the toxicity, of meltwater.

> About two-thirds of the annual sediment, organic, nutrient, and lead load, and virtually all of the chloride load from urban areas are produced by snowmelt and early spring rainfall events.

Alley and Ellis[1] recorded mean meltwater lead levels of 0.7 mg/l, and similarly high concentrations of several other trace metals in Denver, Colorado. Bannerman, *et al.*[2] reported the highest annual concentrations of TSS, Cl, lead, and total zinc were recorded in meltwater and early spring rainfall events in most of their Milwaukee, Wisconsin monitoring sites. They also noted that significant loads of sediment and trace metals are produced during this short interval, with 20-33% of the annual load being contributed.

This finding is consistent with Minnesota meltwater where a substantial amount (about 65%) of the annual sediment, organic, nutrient, and lead load, and virtually all of the chloride load from urban areas are produced by snowmelt and early spring rainfall events.[19] Total loads of pollution are often of more concern than concentration, depending upon whether the receiving water is most sensitive to the strength of a pollutant or to total accumulation. For example, lakes respond to nutrient loads, whereas aquatic life in a stream are more likely to be concentration sensitive and react to the peak concentrations of the toxic materials.

Conclusions

Snowmelt runoff comes from short duration, chemically driven events and from longer duration, end-of-season events. Meltwater runoff carries pollutants that have accumulated all winter in the snowpack, as well as street and soil surface material that washes off of these surfaces. Atmospheric fallout, industrial activity, vehicular emissions/corrosion/fluid leaks, roadway deterioration, urban litter, and anti-skid grit and chemical deicers are sources of the solids, nutrients, and toxic materials that accumulate in a snowpack. Soluble pollutants are preferentially leached or purged from the snowpack in the early stages of the melt. Later melt stages carry the particulate fraction along with a large volume of meltwater, which also washes pollutants from the urban surface.

An understanding of snowpack and snowmelt dynamics is useful to develop effective techniques for treating snowmelt runoff. Different techniques should be employed at each stage of the meltwater sequence, so as to effectively address the constantly changing flows and pollutant concentrations that occur as the melt progresses. A list of some effective techniques is provided in Table 3.

Table 3: Watershed protection techniques for snow and snowmelt conditions

- Use of De-icing Compounds
  - Use alternative de-icing compounds such as $CaCl_2$ and calcium magnesium acetate (CMA)
  - Designate "salt-free" areas on roads adjacent to key streams, wetlands, and resource areas
  - Reduce use of de-icing compounds through better driver training, equipment calibration, and careful application
  - Sweep accumulated salt and grit from roads as soon as practical after surface clears
- Storage of De-icing Compounds
  - Store compounds on sheltered, impervious pads
  - Locate at least 100 feet away from streams and flood plains
  - Direct internal flow to collection system and route external flows around shelters
- Dump Snow in Pervious Areas Where It Can Infiltrate
  - Stockpile snow in flat areas at least 100 feet from stream or floodplain
  - Plant stockpile areas with salt-tolerant ground cover species
  - Remove sediments and debris from dump areas each spring
  - Choose areas with some soil-filtering capacity
- Blow Snow from Curbside to Pervious Areas
- Operate Stormwater Ponds on a Seasonal Mode (Refer to Technical Note 16)
- Use Level Spreaders and Berms to Spread Meltwater Over Vegetated Areas
- Intensive Street Cleaning in Early Spring can Help Remove Particulates on Road Surfaces

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This Open Forum is devoted to the question of whether specific, numerical limits on total watershed imperviousness are a practical and defensible zoning tool to protect stream quality in developing areas. On the face of it, such limits would seem to be an ideal approach. Clearly, the most reliable, conservative and absolute watershed protection technique is land use control. This rather self-evident proposition is similar to the argument that abstinence is the most reliable technique to prevent pregnancy, or that driving at the posted speed limit will sharply reduce one's chance of being in a car wreck. Each of these prescriptions involves a sensible degree of self restraint, which, regrettably, is seldom practiced.

Given the irresistible lure of economic growth, most communities will continue to develop their watersheds. At the same time, they still want to protect streams from the cumulative impact of that growth. Consequently, our land use control proposition is usually reformulated to: "How much development can a watershed reasonably withstand?", or in particularly fast growing areas, "What is the last possible increment of development that can be squeezed in before a stream ecosystem completely falls apart?" Most observers agree that some limits to growth exist for sensitive watersheds. The critical issues are exactly how high or low these limits are, are they scientifically and legally defensible, and how much can these limits be increased through the use of better environmental technologies. We present two contrasting points of view.

Should Numerical Imperviousness Be Used to Zone Watersheds?

PRO

Dawn Zoner,
Watershed Activist

For a decade, we have known that increasing watershed imperviousness negatively influences the quality of urban streams. Even at relatively low levels of imperviousness, we see profound and often irreversible impacts to the hydrology, morphology, water quality, habitat, and biodiversity of streams. The few studies that have tried to show a functional relationship between imperviousness and stream biodiversity have shown a consistent and disturbing pattern. In short, stream biodiversity declines sharply at about 10 to 15% imperviousness. Physical and hydrological degradation is seen at even lower levels.

Stream biodiversity declines sharply at about 10 to 15% imperviousness.

I also like to cite the 45 minute rule, i.e., it takes about that much time for fly-fisherman to drive out of an urban watershed to find a good riffle to cast his or her fly. I would challenge those that assert that the evidence for impervious limitations is too skimpy to find an exception to this rule anywhere in the country.

We can no longer gamble on technology alone to protect our watersheds. Best management practices are

(continued first column next page)

CON

Noah Moore Limitz III,
Development Attorney

I cannot disagree with the proposition that there are limits to urban growth. The problem is we still do not know exactly what these watershed limits are. Most of the supporting data for imperviousness limits is derived from anecdotal sources, or limited to a specific geographic or physiographic context. Indeed, as more careful and controlled research is performed, I suspect that different limits will be discovered for each physiographic region of the country.

The concept of impervious limits is overly simplistic since it relies on statistical relationships between a fixed variable and notoriously dynamic biological populations. Fish and aquatic insect populations increase and decrease all the time in undisturbed watersheds. A great deal more sophisticated watershed research will be needed before these limits can be considered a legally defensible and enforceable planning tool.

The proponents of impervious limits are "salmonoid-centric" in their environmental vision.

Indeed, the proponents of impervious limits are "salmonoid-centric" in their environmental vision. Their insistent focus on fish diversity ignores many equally compelling non-

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PRO *(continued first column previous page)*

only partially effective in mitigating the impacts of development, and few communities have yet solved the problem of how these practices will be properly maintained over a span of decades. Indeed, despite the millions of dollars spent in constructing BMPs, I am not aware of a single watershed-wide assessment that has demonstrated that they really work. BMPs are needed, but only land use control can provide a guarantee of success for watershed protection.

No other watershed protection technique is as effective or reliable as impervious limits. They are an elegant regulatory tool because imperviousness is so easy to measure, and so easy to alter. Watershed limits force developers and engineers to create developments that are impervious. They represent a fundamentally different approach to development that is not as burdensome as it seems. This is because so many impervious areas in our landscape are not needed. We design roads that are too wide and too long, parking lots that are twice average capacity, and homes that are too far away from each other. With some ingenuity, high quality economic development can still continue under watershed imperviousness limits.

BMPs are needed, but only land use control can provide a guarantee of success for watershed protection.

Impervious limits are but one component of watershed-based zoning. This approach accepts the notion that some watersheds must be developed beyond the stream's biological capacity in order to compensate for those watersheds where development is limited. Under watershed- based zoning, future urban growth is directed back to watersheds that have already been degraded by previous development activity. In many cases, the quality of these degraded watersheds can be maintained or even improved through community watershed restoration techniques.

Impervious limits can be adopted now and refined later. We need to act now. Otherwise when the last watershed study is finally completed, the stream will be dead.

CON *(continued second column previous page)*

point source issues such as shellfish bed closures, nutrient loading to lakes and estuaries, sedimentation, human health (remember cryptosporidum?). How, precisely, will these water resource problems be folded into the concept of impervious limits?

As surprising at it may seem, developers don't like imperviousness—it costs us money to pour concrete. The only imperviousness a developer likes to see is rooftops, and they represent only a modest share of total imperviousness. Antiquated subdivision codes require us to make our roads so wide, our parking lots so vast, and cluster development an unrealized dream. Until local governments reform these dusty codes, any impervious limits would just be a growth moratorium in disguise.

Until local governments reform these dusty codes, any impervious limits would just be a growth moratorium in disguise.

Impervious limits would also create some perverse and unintended side effects in our landscape. For example, the ten percent limit frequently cited would almost surely encourage the proliferation of low density sprawl over a much wider geographic pattern than would otherwise occur. Growth, and the infrastructure to support that growth, will spread and leapfrog across many watersheds.

Although the proponents of impervious limits do talk loosely about sacrificing some highly developed watersheds to compensate for their scheme, they always seem to be the ones they don't live in (strangely, their residents are usually people of color).

Impervious limits, like many simple ideas, will always be attractive to environmentalists. But the zoning process is a complex and democratic affair involving many diverse interests. We need to zone not only for fish, but also for people, jobs, recreation, traffic, sewers, services, and the quality of our community. This mix of factors can only be reconciled within the context of a locally crafted watershed study—not through inflexible limits on impervious surfaces.

Editors Note:

The next issue of Techniques will contain several feature articles on the subject of subdivision code reform and current research on the links between imperviousness and stream quality. Please send us your opinions on this subject, as well.

Technical Note 16

Performance of Stormwater Ponds and Wetlands in Winter

By: Gary Oberts, Metropolitan Council, St. Paul, MN

Stormwater ponds and wetlands are common techniques for treating stormwater runoff in northern regions. Until recently, however, very little winter monitoring data was available. Oberts and his colleagues sampled four stormwater ponds in Minnesota during both rainfall and snowmelt conditions. They found that ponds were generally effective in removing pollutants during non-winter conditions. There was, however, a marked reduction in the performance of stormwater ponds in treating snowmelt runoff. Most ponds did a fair job of removing sediment and organic matter in the winter, but were mediocre in removing nutrients and lead (Figure 16.1).

Until recently very little winter monitoring data was available

There are several reasons for the poor performance of stormwater ponds in winter. One primary reason is the thick ice layer that can form, sometimes reaching three feet in depth. This ice layer can effectively eliminate as much as half of the permanent storage volume needed for effective treatment of incoming runoff. In this case, the first increment of meltwater runoff entering the pond dives beneath the ice layer and create a turbulent, pressurized condition which scours and resuspends bottom sediments in the pond.

Once the available pool volume under the ice is filled, meltwater runoff is then forced to flow over the top of the ice. This further reduces performance since the settling depth above the effectively impermeable ice layer is minimal. Pollutants that settle on the ice are easily resuspended during the next melt or runoff event. In addition to the physical limitations of settling, biological activity in the pond is also greatly reduced during the winter.

The same forces working against wet stormwater ponds in winter also work against wetland systems. In fact, wetland efficiency may drop even further because they are shallower, have larger

Figure 16.1: Average effectiveness of four stormwater ponds **(adapted from Oberts, et al., 1989)**

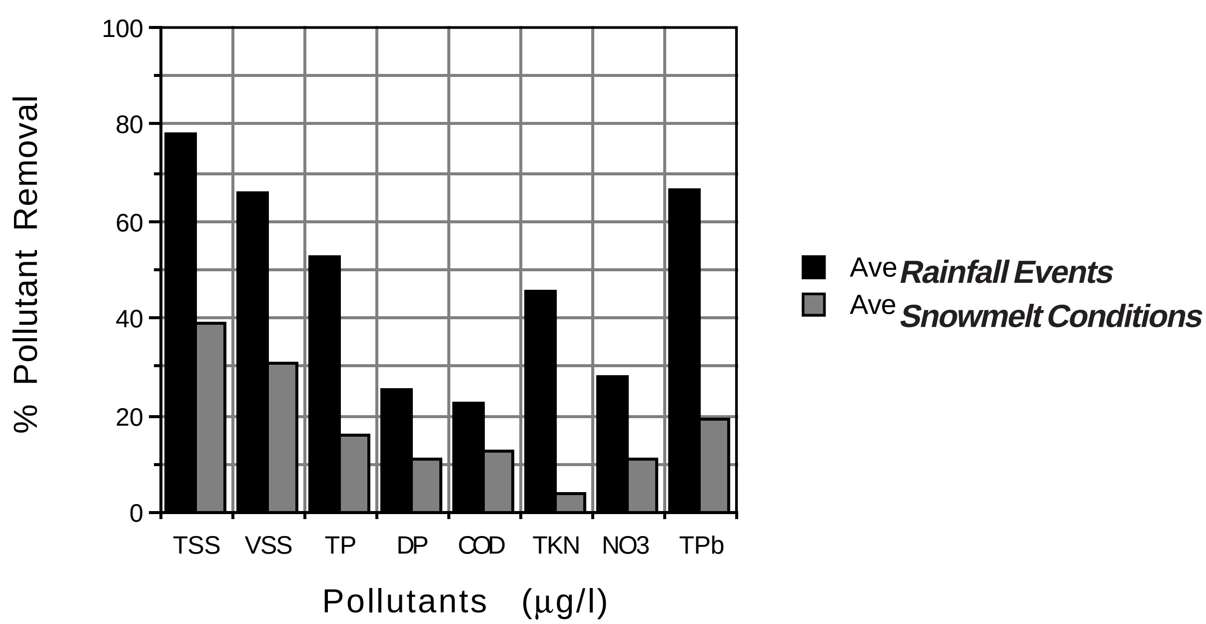
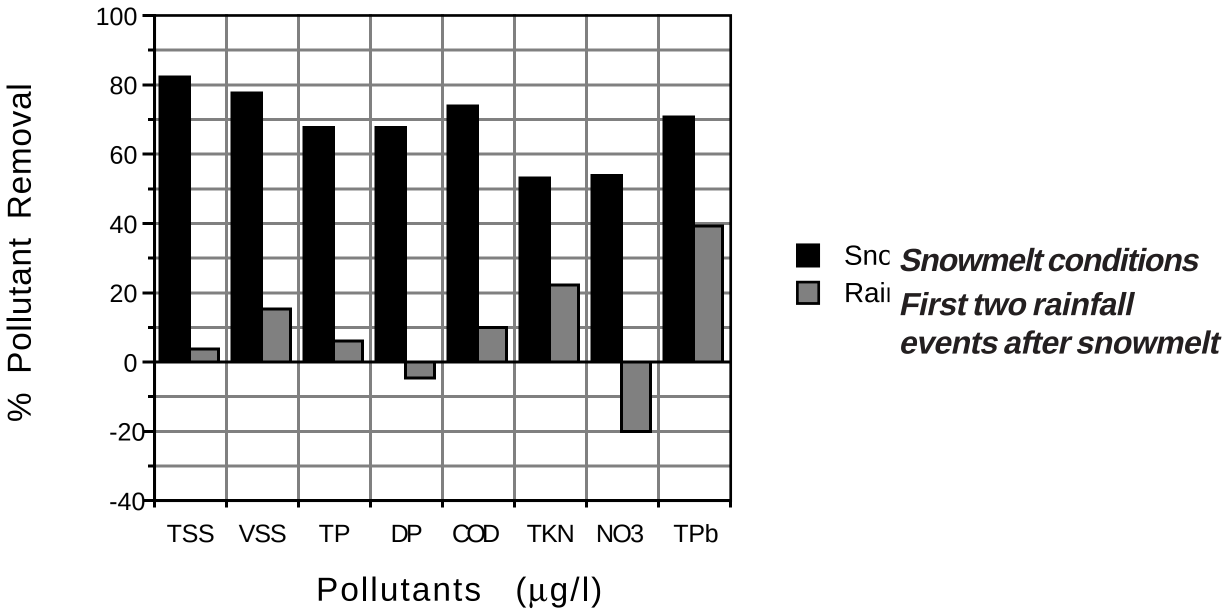


Figure 16.2: Effectiveness of a MN wetland treatment system *(Oberts and Osgood, 1988)*



amounts of detritus available for resuspension, and are biological dormant during winter.

Research on a wetland in Minnesota shows how pollutants can pass through a stormwater wetland system, even when it appears as though the system might be working. The pollutant removal performance during snowmelt and for the first two rainfall events after snowmelt in a 2.5 ha, six-chambered, lowhead wetland treatment system is presented in Figure 16.2. The wetland outlet was frozen for the entire winter and was thus effectively closed. This resulted in the formation of a thick ice layer and subsequent deposition and accumulation of all small midwinter events and baseflow in the final wetland chamber (approximately 1 ha). When the end-of-season melt began, runoff entering the final wetland cell ponded and dropped a portion of its load on top of the ice layer. Water began to move downgrade only when an opening in the outlet culvert formed. The material that settled was subsequently washed away by the next rain occurring after the snowpack had entirely melted from the catchment.

Are there design methods that can improve the performance of stormwater ponds during snowmelt conditions?

Meltwater Treatment

The first meltwater from a snowpack will likely be acidic and highly concentrated with soluble pollutants, particularly ions (Na^+, Ca^{2+}, SO_4^{2-}, Mg^{2+}, H^+, NO_3^-). Adverse impacts of meltwater on aquatic life are typically related to elevated levels of metals, organic toxicants, and salt. Thus meltwater treatment should occur before it reaches a receiving waterbody. One treatment is to detain it so that it can infiltrate into the soil where soil adsorption and macrobiotic activity can occur (Zapf-Gilje, *et al.*, 1986).

Hartsoe (1993) found that PAHs were essentially non-detectable in groundwater infiltrating through sand and gravel at a highway drainage infiltration pond in Minnesota. However, the most soluble meltwater pollutants, such as chloride, will likely pass through the soil relatively intact. This phenomenon should be taken into account when designing such a facility.

The first meltwater from a snowpack should be treated before it reaches a

Two alternatives for meltwater treatment are shown in Figures 16.3 and 16.4. The first option (Figure 16.3) is a nonstructural approach wherein meltwater is routed through an infiltration swale (e.g., grass, sand/gravel) to a flow diffuser that spreads the meltwater over a naturally vegetated or wetland surface. Even though the vegetation is dormant, some benefit will occur because the area will likely be able to infiltrate some water. Caution must be exercised, however, since chlorides and other ions can adversely impact the grass or wetland areas and induce a shift to less desirable plant species.

Meltwater infiltration can also be accomplished using a gravel level spreader that acts as a diversion channel. This simple feature can be incorporated into many different kinds of meltwater handling systems. The diversion channel can be used to route highly concentrated water around a particularly sensitive receiving water or into a best management practice.

The second option for meltwater treatment is an infiltration-detention basin that incorporates two design features to enhance meltwater treatment (Figure 16.4). The first feature is a variable outflow control structure that allows for drawdown of the water level to increase runoff storage. The second feature is an underdrain with a control valve to drain the porous bottom substrate in the Fall. The goal is to decrease the moisture levels that lead to an impermeable layer of frozen soil.

Seasonal ponds are drawn down during fall to prevent the formation of an ice

Both the underdrain and outflow controls should be closed prior to the Spring melt in preparation for runoff treatment. Once the melt begins, the initial function of the basin is to promote the infiltration of the "first flush" of meltwater. As the melt event proceeds and reaches its peak end-of-season flow, the basin acts as a detention facility, since inflow to the pond will exceed the infiltration capacity of the soil. Critical design features include the underdrain, the relatively flat slopes, soil type, and the predicted end-of-season snowmelt volumes that will discharge into the basin.

Local groundwater quality must be considered since the first meltwater entering the basin may contain soluble pollutants that could migrate through the substrate. Even though a very large volume of meltwater enters the basin, the combination of added detention with enhanced infiltration may dampen the "shock" effect of the highly concentrated first melt.

Additionally, the available storage helps to settle some of the particulate pollutants that leave the snowpack last. A basin of this type requires active management to assure desired infiltration capabilities are maintained and to regulate storage and substrate conditions.

Seasonal Stormwater Ponds

A conceptual design for a "seasonal" pond that might overcome ice layer problems is shown in Figure 16.5. Water is drawn down in the Fall from the pond to prevent the formation of a layer of ice at the normal summer elevation.

A low-flow channel discourages the formation of channel ice. The channel, which must have a high velocity, helps move baseflow and small melt through the pond during the winter and prevent ice buildup. As the melt progresses and meltwater flows increase, the lower outlets are closed, allowing the pond to again act as a normal detention pond, capable of impounding water to summer design levels.

Other Pond Design Considerations

When drawdown is not possible or desirable, there are still some design options to improve the winter performance of stormwater ponds. First, the

Figure 16.3: Minimum structural approach to meltwater treatment

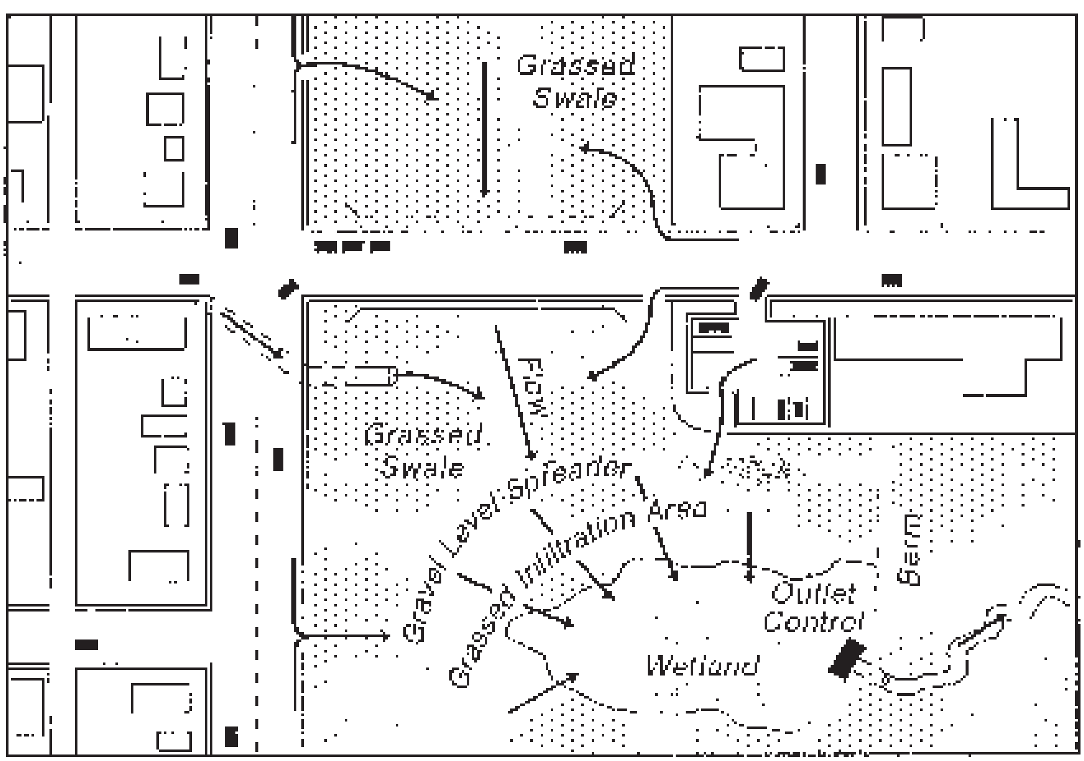


Figure 16.4: Seasonal operation of a stormwater pond

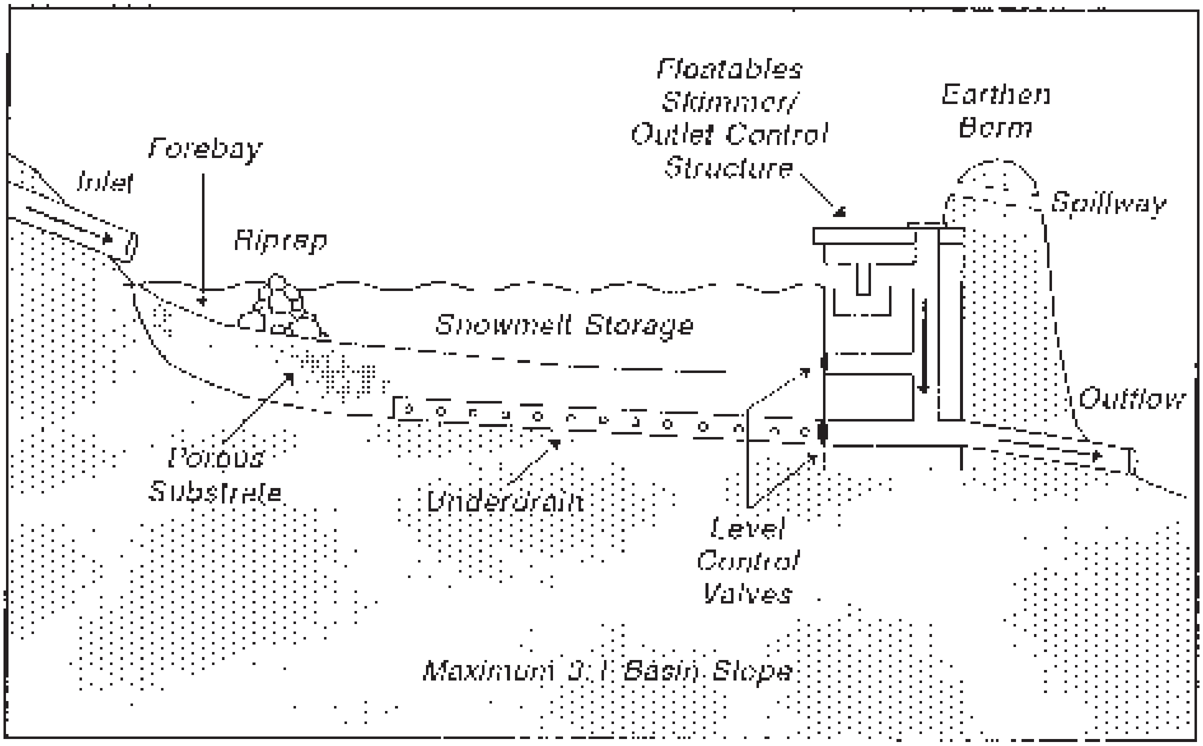
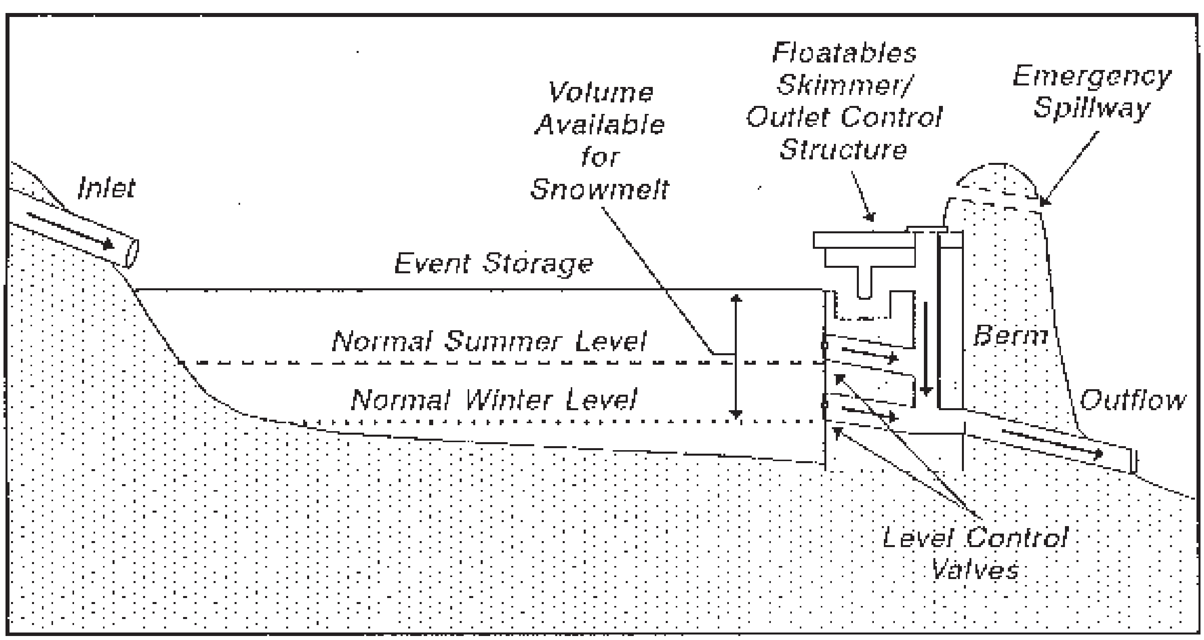


Figure 16.5: Combined infiltration/detention basin



pond bottom should be sloped so that the deepest part is near the outlet. This configuration minimizes scouring of bottom material as water emerges from under the ice on its way out of the pond. Installation of a baffle weir, floatable skimmers, or a riser hood around the outlet can also help keep a constant movement of water below the ice, thus preventing the buildup of ice at the outlet. These measures assure that the outlet remains clear in the winter and can partially reduce the upwelling pressure of runoff from below the ice layer.

Warm weather methods for treating stormwater need to be adapted to effectively

If an ice layer is unavoidable, the outflow device can be totally closed to allow for some detention capacity between the ice layer and the spillway elevation. Overflow can occur via an emergency spillway, provided adequate safety and erosion control measures are taken. Another approach to dealing with ice cover is to prevent its formation through aeration or circulation. This practice can be a safety problem, however, if the public has access to the facility. Thus, aeration or circulation should only be used if safety can be assured.

Other problems are often encountered in the winter months. Ice can form a barrier that interferes with proper flow through the conveyance system. Frozen culverts are a very common occurrence, especially when water velocity is not sufficient to keep water moving or splash occurs which slowly builds a thick layer of ice.

The use of moving parts in stormwater ponds should be carefully scrutinized because of the potential for freeze-up at the time when they are most expected to function (plates/gates, flashboards, valves, or similar controls). Orifice or weir outlet control may be used as an alternative. For example, if a pond is scheduled to be drawn down in the Fall, and there is concern that a movable control valve will freeze in winter, an inserted flashboard or a bolted metal plate over an orifice could be used.

Warm weather methods of treating stormwater need to be adapted to more effectively handle pollutants during snowmelt. Useful approaches include seasonal detention facilities, specially designed outlet structures, meltwater infiltration, off-channel diversion, and aeration/circulation.

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Hartsoe, J.A. 1993. The groundwater impact of polycyclic aromatic hydrocarbons from infiltrating highway runoff. Met. Council, St. Paul, MN. Publ. No. 590-93-036. 88 pp.

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Technical Note 17

Performance of a Stormwater Pond/Wetland System in Colorado

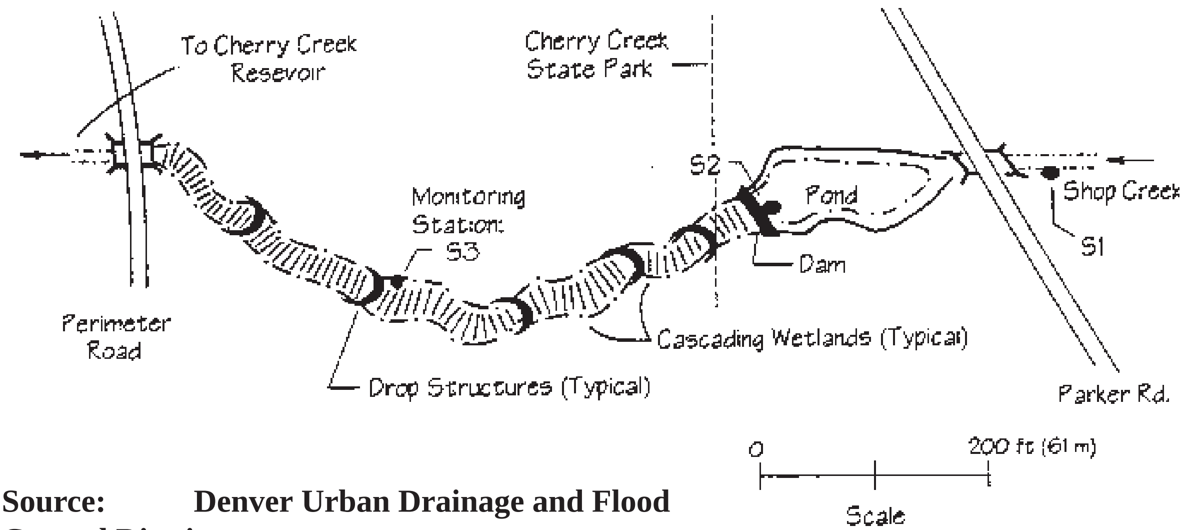
Urbonas and his colleagues recently investigated the pollutant removal performance of a large stormwater pond/wetland system located in Aurora, Colorado. The unique runoff treatment system is illustrated in Figure 17.1. Runoff enters a large wet pond that provided a total of 0.3 watershed-inches of runoff treatment (0.1 inches of permanent pool, plus 0.2 inches of extended detention — approximately 20 hours for most storm events). Runoff then exits the pond over a soil/cement spillway and enters a series of six cascading cells.

Long-term monitoring indicates the importance of assessing pollutant removal during both storm and dry weather periods.

Wetland cells were located in a flat and broad channel, and formed by a soil cement drop structure installed across the channel. Water velocity was designed to be less than 3 feet per second (fps) during major floods, and less than 0.3 fps during smaller storm events. The wetland consisted primarily of cattail and bulrush species. Average contact time in the 3.8 acre wetland area was about two hours during smaller storms. The wetland cells comprised about 0.70 percent of total watershed area.

The Shop Creek watershed draining to

Figure 17.1: Arrangement of the pond-wetland system on Shop Creek



Source: Denver Urban Drainage and Flood Control District

Thirty six storm events were sampled over a three year period in a cooperative effort of the Cherry Basin Water Quality Authority and the Denver Urban Drainage and Flood Control District. Monitoring was confined to the growing season (May to September) in the semi-arid area. In addition, a limited number of baseflow samples were taken along the wet pond and wetland system to characterize water quality dynamics during dry weather periods.

The monitoring revealed that the pond/wetland system was reasonably effective at removing many pollutants during storm events (Table 17.1). For example, about half of the total and dissolved phosphorus load was removed as it passed through the pond, with the majority occurring in the pond rather than the wetland. Likewise, about 72% of suspended sediment was removed by the system, even with a slight export from the wetland component. Removal of total zinc and copper approached 60% for the system. Chemical oxygen demand (COD) was reduced by 56%.

The performance of the pond/wetland system in removing nitrogen, however, was mediocre, due in most part to a large export of nitrate (76%) and to a lesser degree, nitrite. The modest removal of organic forms of nitrogen (30%) could not offset this export of nitrate, which may be in fact due to a large resident waterfowl population. In general, the combined system worked effectively, with the extended detention wet pond providing the bulk of the storm removal. The cascading wetlands helping to polish the quality of runoff during baseflow periods.

The importance of the wetland component was most evident during baseflow periods (Table 17.2). During these dry weather periods, the pond tended to export some pollutants due to biological activity and other processes (e.g., total copper, total iron, total phosphorus, organic nitrogen, and suspended solids).

The slight export of pollutants from the pond was generally compensated by further pollutant removal within the wetland component during dry weather periods. The only exception to this pattern was total copper, which increased by 110% as it passed through both portions of the system.

In summary, the long-term monitoring of the Shop Creek pond/wetland system indicates the importance of assessing pollutant removal during both storm and dry weather periods. The common practice of neglecting baseflow when pollutant removal efficiencies are computed is not a wise idea on pond systems that serve large drainage areas.

The study also supports the trend toward design of multiple and redundant stormwater

Table 17.1: Average removal rates for the pond/wetland system during storms, 1990-1992 ***(Adapted from Urbonas, et al., 1993)***

Parameter	% Removed by Pond	% Removed by Wetland	% Removed by System
Total Phosphorus	49	3	51
Dissolved Phosphorus	32	12	40
Nitrate-Nitrogen	-85	5	-76
Organic-Nitrogen	32	-1	31
Total Nitrogen	-12	1	19
Total Copper	57	2	57
Dissolved Copper	53	-1	58
Total Zinc	51	31	66
Dissolved Zinc	34	-5	30
Total Suspended Solids	78	-29	72
Chemical Oxygen Demand	44	21	56

Table 17.2: Baseflow water chemistry through the Shop Creek pond/wetland system (N=5)

Parameter	Baseflow to Pond	Baseflow from Pond	Baseflow from Wetland	Storm Outflow *
Total Phosphorus (mg/l)	0.11	0.19	0.09	0.20
Dissolved Phosphorus (mg/l)	0.095	0.047	0.07	0.13
Nitrate-N (mg/l)	0.71	0.32	0.22	2.2
Total Copper (µg/l)	15	28	32	15
Dissolved Zinc (µg/l)	15	8	6	32
TSS (mg/l)	7	26	6	33
COD (mg/l)	19	56	24	36

* average concentration of storm outflow from pond-wetland system

treatment systems to provide more reliable pollutant removal over a range of runoff conditions.

—*TRS*

Reference:

Urbonas, B., J. Carlson, and B. Vang. 1994. Joint pond-wetland system in Colorado, USA. An Internal Report of the Denver Urban Drainage and Flood Control District.

Contact:

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Technical Note 18

Innovative Nutrient and Sediment Control System Developed for Maine

The Nutrient and Sediment Control System (NSCS) has been developed in Northern Maine by the Soil Conservation Service to remove pollutants in cropland runoff. The basic NSCS design, shown in Figure 18.1, includes a series of six best management practices in a compact arrangement.

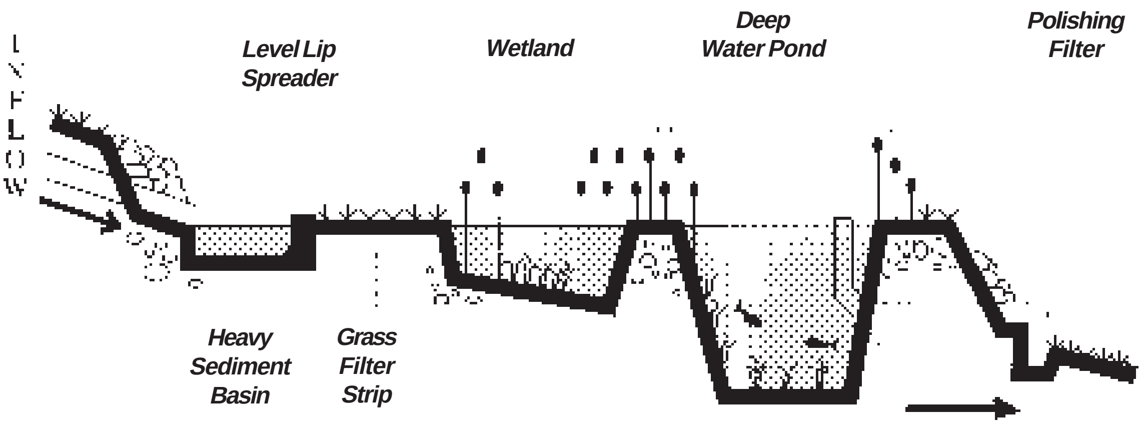
Runoff enters a sediment basin, passes over a level spreader that diverts sheet flow across a grass filter strip. The effluent from the grass strip is then routed into a shallow wetland, that, in turn feeds into a deep pond. Outflow from the deep pond is then routed into a second level spreader that distributes flow into a grassed or forested filtering area. After runoff is polished in the filter area, it is directed into the stream.

To date, eight NSCS systems have been installed in Maine, with most installed on potato and corn fields from 20 to 160 acres. The exact configuration and size of each system varies depending on watershed area, slope, and space constraints. According to the specifications provided by USDA (1993), a NSCS serving 25 acre of crops would be about an acre in size and provide about 1.0 watershed-inch of runoff storage. Space consumption for a 150 acre facility is about 3 acres. Construction costs, exclusive of land, planning, and design, are reported to range from $14,000 to $38,000. The NSCS is eligible for 80% cost share as an agricultural best management practice.

The NSCS has a number of interesting design features. The sediment basin is long and narrow, with a ramp on one end to allow easy access for sediment cleanout. The level spreader is formed by an earthen berm with a stone core trench. This ensures that sheetflow is maintained into the grass filter strip. The strip is drained by sub-surface tile drains to prevent saturation of the surface soils. This not only keeps the surface soils aerobic (promoting more vigorous grass growth), but also allows for drier mowing conditions. The shallow wetland is established with Cattail *(Typha latifolia)* or bulrush *(Scirpus americanus)*, usually over a prepared substrate of four inches of topsoil.

The core of the NSCS system, however, is the deep pond. It is a minimum of 8 feet deep (maxi-

Figure 18.1: The nutrient and sediment control system



Source: St. John Valley Soil and Water Conservation District

mum of 12) and comprises about 75% of the total runoff storage of the entire system. The outflow from the pond consists of a drop inlet pipe spillway which might help to aerate the bottom water from the pond. The polishing filter is often an optional design feature, and can be forest, meadow, or sod-forming cool season grasses.

The truly unique aspect of the system is its emphasis on biological treatment mechanisms in the pond. For example, the specifications require that the pond be stocked with freshwater mussels at the rate of 100 per 3,000 square feet of pond surface area. The mussels are use to filter pond water, which they do with some vigor. Each mussel typically filters about 10 gallons per day. A healthy population of mussels has the capability to completely filter the deep pond in 30 to 60 days.

The specs also call for stocking the deep pond with baitfish (usually cyprinids such as shiners) at the rate of 250 baitfish per 5,000 square feet of pond area. Again, the purpose is to utilize the fish to feed on plankton in the pond, and thus incorporate nutrients into biomass. A third biological specification is a requirement to establish the submerged aquatic plant, Sago pondweed *(Pomategeton pectinatus),* in the transition area between the pond and wetland.

The prescribed management regime for the system involves harvesting of grass in the filter strip, biomass in the shallow wetland, and baitfish in the deep pond. The extent to which harvesting actually occurs is not clear. Other maintenance requirements include mowing the filter strip and periodic cleanout of the sediment basin. The NSCS appears to function reasonably well even in the extremely cold winters of Maine. This is partly because the system lacks obstructions where ice jams could occur, and partly because the pond outlet is several feet below the surface.

Performance monitoring of the NSCS has been limited to data collection of sediment and phosphorus removal. Based on results from two summer monitoring seasons, the system does appear to be very effective in removing both sediment and phosphorus. Storm removal rates in excess of 90% are reported, even during extreme events, such as a 50-year return frequency storm (Wengrzynek,1992). This compares favorably with the highest removal achieved by urban stormwater pond/wetland systems (See Notes 6 & 17).

A unique aspect of the system is its emphasis on biological treatment

Wengrzynek notes that outflow from the system is quite rare during most small and moderate-sized rainstorms. This undoubtedly reflects the large runoff storage capacity of the entire system in relation to its modest runoff inputs from agricultural areas. If the contributing watershed were in condos as opposed to potatoes, for example, the system would have to handle 5 to 20 times more annual storm runoff volume. As a consequence, it is not clear whether the NSCS system could maintain such high pollutant removal rates under urban watershed conditions.

The Soil Conservation Service plans to expand the use of the NSCS to other agricultural regions, and also expects to eventually adapt it to treat stormwater runoff from urban areas. The NSCS provides another example of how greater reliability in runoff treatment can be achieved when a combination of different BMPs are used and biological opportunities for pollutant removal maximized.

—TRS

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Contact:

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Technical Note 19

Water Reuse Ponds Developed in Florida

Stormwater runoff can become a valuable water resource in many regions of the country. This novel perspective has led to the development of *water reuse ponds*. The basic principles are quite simple. Stormwater runoff is captured and stored in a pond, and then pumped back out to irrigate pervious areas in the contributing watershed. These areas can include golf courses, cemeteries, landscaping, community open space, and turf areas.

The design is similar in many respects to a wet extended detention (ED) pond. Each has four distinct storage components—sediment or forebay storage, flood control storage, pool storage, and temporary storage. The key difference is that, in water reuse ponds, temporary storage is gradually pumped out for irrigation, whereas in wet ED ponds, it is gradually released downstream over a 24-hour period. During an extended dry weather period, continued pumping of the water reuse pond can draw down water levels in the permanent pool.

Water reuse ponds are expected to achieve even greater mass pollutant removal rates than standard stormwater ponds.

Water reuse ponds have several key environmental and economic benefits. The greatest benefit is the increased pollutant removal and groundwater recharge that occurs because a large fraction of the annual stormwater runoff volume (and pollutant load) are applied back to the watershed. Consequently, water reuse ponds are expected to achieve even greater mass pollutant removal rates than standard stormwater ponds. Without reuse, ponds cannot reduce the volume of runoff delivered downstream, and must rely exclusively on pollutant removal pathways within the pond to capture and treat stormwater pollutants.

Water reuse ponds are also a particularly useful design option where the water table is close to the land surface. Continuous pumping helps maintain storage capacity that would otherwise be lost due to groundwater intrusion.

The key economic benefit of water reuse ponds is that they are a relatively cheap source of irrigation water, when compared to the cost of potable water supplies. For example, Wanielista and Yousef (1993) calculate that the cost of irrigating a 100 acre, 18 hole golf course (two inches per week) may cost the operator nearly $300,000 a year if potable water is used. By contrast, the annual irrigation cost of pumped stormwater from a water reuse stormwater pond was seven times lower (about $40,000/year).

Two questions are often asked about water reuse ponds:

- how much stormwater storage is needed to assure a reliable irrigable water supply? and;
- how much stormwater runoff actually leaves the pond? Put another way, is it possible to design a "zero-discharge" pond?

To answer these questions, Wanielista and his colleagues simulated a water reuse pond in Florida using 15 years of daily rainfall, runoff, reuse, and pond discharge data. The heart of the model is a pond water balance that computes changes in incoming runoff, groundwater, direct rainfall to the pond, irrigation, pond outflow, storage, evapo-transpiration, and other hydrologic terms.

The model accurately simulated the actual performance of a monitored water reuse pond in Orlando, Florida. It was then used to construct a series of rate-efficiency-volume (REV) curves. These curves are a helpful aid in designing water reuse ponds. While REV curves are presently available only for Florida, the basic modeling approach is transferable to other regions of the country.

An analysis of the Florida curves suggest that water reuse ponds can provide a reliable source of irrigable water over the long term if a sizeable reuse volume is provided (often in excess of the local water quality volume). At this size, as much as 50 to 90% of the incoming runoff will be recycled back on the land, depending on the irrigation rate.

Water reuse ponds do have a few drawbacks. For example, they require a greater degree of operation than other BMPs, as well as the presence of a nearby customer for irrigation water. Also, reuse ponds may not be appropriate in sensitive streams, as continued pumping could diminish or eliminate downstream flows needed to sustain aquatic life. Nevertheless, they are a potentially useful pond design option in many climatic regions where irrigation is needed in urban areas on a seasonal or year-round basis.

—TRS

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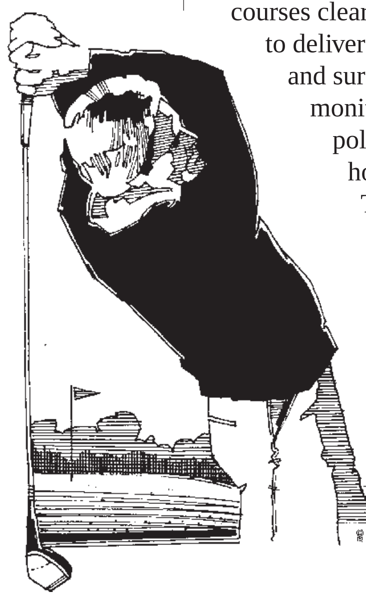
Technical Note 20

Minimizing the Impact of Golf Courses on Streams

Over 13,000 golf courses now exist in the U.S. and many more will be constructed to meet the growing popularity of the sport. The construction of a new golf course has the potential to create adverse impacts on the aquatic environment. To begin with, a typical 18 hole golf course can convert as much as 100 acres of rural land into a highly "terra-formed" environment of fairways, greens, tees, sand traps, and water hazards. As such, golf courses are often an attractive part of the urban landscape. Haphazardly designed golf courses, however, can disrupt and degrade the wetlands, floodplains, riparian zones, and forests that contribute to stream quality.



A second recurring concern about golf courses are the large inputs of fertilizer, pesticides, fungicides, and other chemicals that are required to maintain vigorous and attractive greens. In many cases, chemical application rates can rival and even exceed those used in intensive agriculture. Table 20.1 shows a side by side comparison of chemical application rates for a coastal plain golf course and cropfield in Maryland, as reported by Klein (1990).

The actual rate of fertilizer and pesticide application rates at a particular golf course can vary considerably, depending on the soil, climate, and management program. As an example, fungicides and nematicides are only lightly used in regions with cold winters, but constitute a major fraction of total pesticide applications in warmer climates. Given such intensive use of chemicals, golf courses clearly have the potential to deliver pollutants to ground and surface waters. Actual monitoring data on pollutant loads from golf courses, however, are quite scarce (but see Technical Note 27).

Golf course chemical application rates can rival and even exceed those used in intensive agriculture.

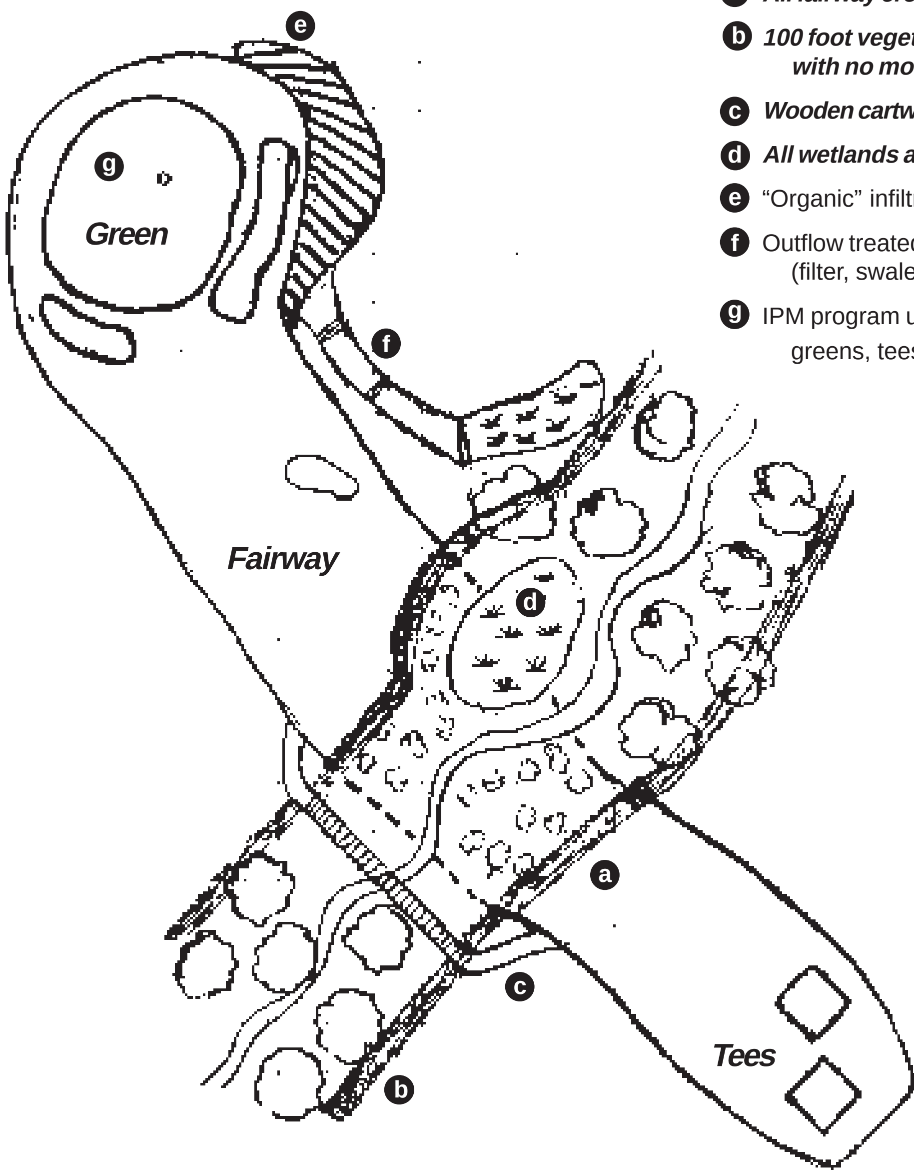
Golf courses are also intensive water consumers, particularly in drier regions of the country. This need for irrigable water can place strong demands on local groundwater and/or surface water supplies, which in turn, can cause baseflow depletion. In addition, the construction of the ubiquitous golf course water hazards can lead to downstream warming in sensitive trout streams.

In the late 1980's, Baltimore County, Maryland was confronted with a wave of golf course development proposals and strong concerns about the possible risk they might have on their Piedmont streams. The Department of Environmental Protection and Resource Management drafted and revised a series of environmental guidelines for new golf course construction. The guidelines stress the importance of integrating the layout of the course with the natural features of the site.

***Table 20.1: Comparative chemical application rates for a Maryland golf course and corn/soybean rotation. Reported in pounds/acre/year* (adapted from Klein, 1990)**

Chemical	Cropland	Fairway	Greens	Tees
Nitrogen	184	150	213	153
Phosphorus	80	88	44	93
Herbicides	5.8	10.4	10.2	11.4
Insectcide	1.0	2.0	2.0	2.0
Fungicide	0.0	26.9	34.9	26.9
Total Pesticides	5.8	37.3	45.1	38.3

Figure 20.1: Best management practices for a golf course and stream crossing **(adapted from Powell and Jolley, 1992)**



- **a** ***All fairway crossings are perpendicular to the stream***
- **b** ***100 foot vegetated buffer maintained along the stream, with no more than two crossings per 1,000 feet***
- **c** ***Wooden cartway crossing on wooden pilings***
- **d** ***All wetlands are protected with extra buffer***
- **e** "Organic" infiltration trench treats green leachate
- **f** Outflow treated by a combination of vegetative BMPs (filter, swale, wetland)
- **g** IPM program used to reduce chemical applications to greens, tees, and fairways

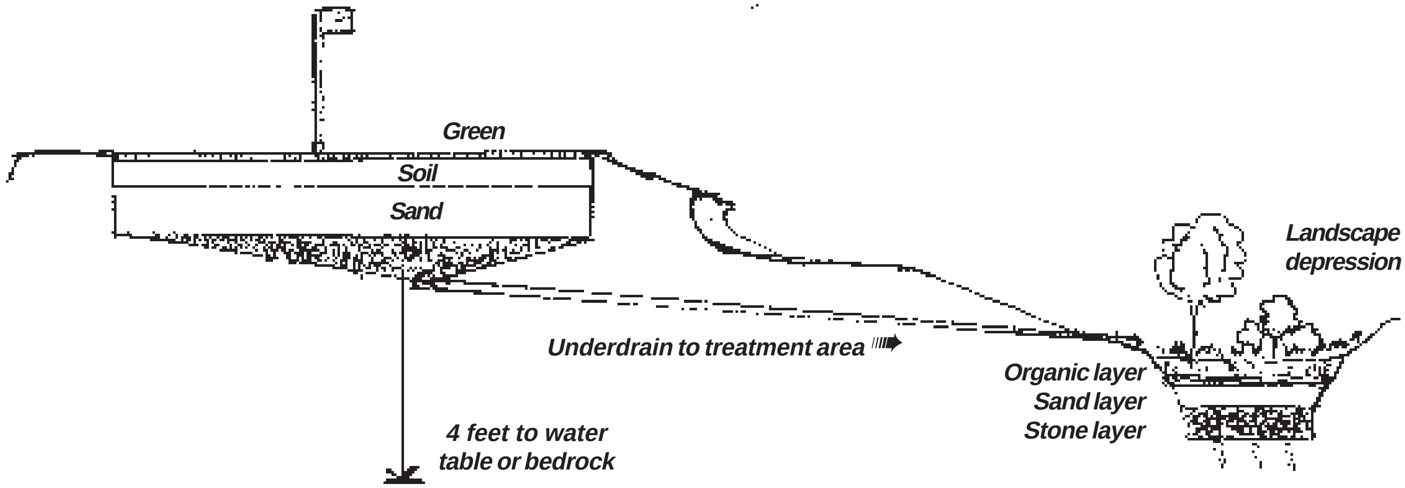
For example, the guidelines require a detailed evaluation of wetlands, perennial and intermittent streams, floodplains, slopes, forest stands and habitat features at the proposed course. The course must be configured to avoid or minimize disturbance to these resource areas. In this respect, long broad fairways are a prime culprit, as they frequently cross or encroach into streams and other buffer areas.

Long broad fairways are a prime culprit, as they frequently cross or encroach into streams and

Consequently, the guidelines devote a great deal of attention to the issue of fairway crossings (see Figure 20.1). For example, no more than two fairway crossings are allowed for each 1,000 feet of stream length. These crossing must be perpendicular to the stream. If forests or wetlands are present at the crossing, this zone must be managed as unplayable rough and remain undisturbed as early successional forest or wetland.Cartways and footpaths that cross the stream corridor must be narrow and constructed of timber on wooden pilings. The County guidelines also limit the extent of forest that can be cleared during construction. No more than 25% of the pre-existing forest cover may be removed during course construction.

Constructed ponds are not permitted in trout streams unless they are "zero discharge" facilities

Figure 2: Schematic of a water quality treatment system to remove pollutants from a golf course green



constructed in upland areas (see Technical Note 19). Best management practices emphasize treatment of greens and tees where nutrient and pesticide applications are greatest. The use of a series of vegetative filtering mechanisms such as swales, forest buffers, sand filters, and infiltration trenches are recommended.

A common practice for greens is illustrated in Figure 20.2. To start with, a four foot thick mantle of soil is required below the green's underdrain system to prevent leachate from entering groundwater. The leachate is collected in perforated pipes and routed into small depression. This depression is usually filled with layers of organic matter, sand and stone, and then landscaped. The depression acts as both a biofilter and an infiltration facility.

Excess runoff from fairways is also treated by a series of best redundant best management practices (e.g., a grass swale leading to a pocket wetland or irrigation pond that in turn overflows into a forest buffer strip).

Since golf courses are largely pervious in nature, it is not always appropriate to size BMP systems for water quality treatment based on conventional water quality sizing rules (i.e., based on the amount of impervious area created at the site). Rather, it is more important to ensure proper control of each green, tee, and faiway, and to maximize the use of swales, forest buffers, and wetlands to achieve high rates of treatment.

The Baltimore County guidelines require the installation of permanent sampling wells in addition to periodic monitoring of storm runoff, groundwater, and the biological community present in golf course streams. The guidelines also recognize the importance of integrated pest management (IPM).

The golf course operator must submit an IPM plan that emphasizes the selection of drought and disease resistant turf that requires less maintenance, utilizes biological controls rather than chemicals, and carefully regulates the selection and application of pesticides. The use of slow release fertilizers is also encouraged to minimize the leaching of nitrates into groundwater.

To date, the guidelines have been applied to seven new golf course development proposals in Baltimore County with the active cooperation from the golf design community. Preliminary storm and groundwater monitoring data from several golf courses designed under the new guidelines indicate that they appear to have little impact on water quality, with the possible exception of nitrate leaching. Additional storm monitoring data is expected at both public and private courses over the next two years to attempt to confirm this observation.

—TRS

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Technical Note 21

A Second Look at Porous Pavement/Underground Recharge

By: Thomas Cahill, Cahill Associates

The optimal stormwater management techniques prevent both water quality and quantity impacts. In theory, techniques which rely on maintaining the mechanism of soil infiltration are ideal. Allowing the hydrologic cycle to continue in a pre-disturbance condition, so that aquifers are recharged and increased surface runoff pollutant loadings are prevented, is clearly the goal. However, practical engineering solutions based on the infiltration concept have been difficult to design and even more challenging to implement.

Contrary to prevailing wisdom, porous pavement/underground recharge bed BMP applications *can* be developed successfully.

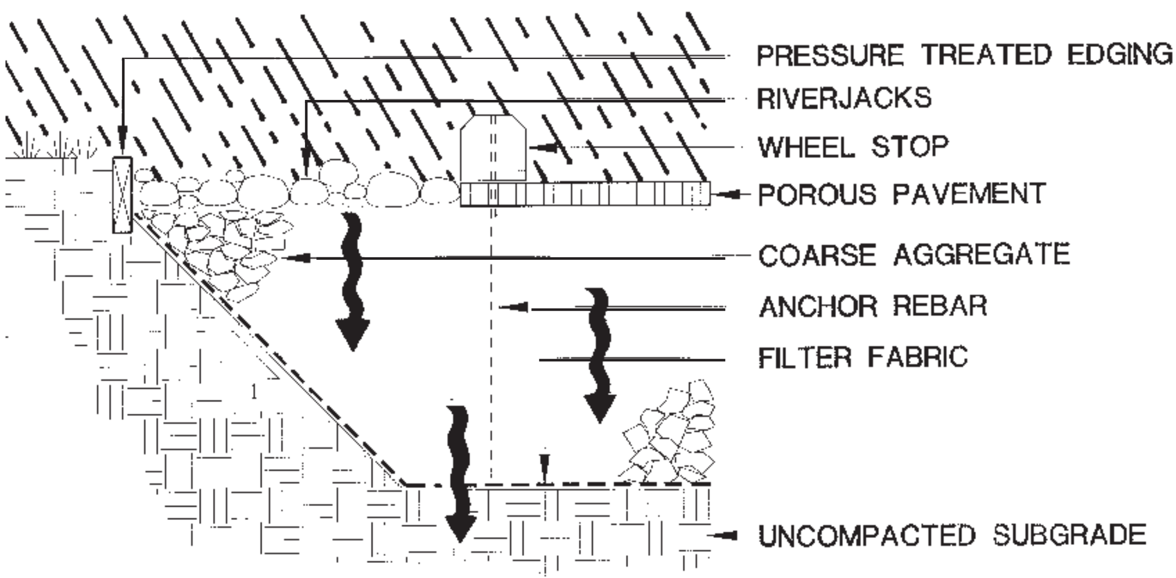
The quandary is illustrated vividly by porous pavement, a technique proposed over twenty years ago. After numerous unsuccessful installations, use of porous pavement is routinely rejected by most engineers, designers, and stormwater program developers. Contrary to prevailing wisdom, however, porous pavement/ underground recharge bed BMP applications *can* be developed successfully.

Cahill Associates (CA), a suburban Philadelphia environmental engineering firm, has been designing and constructing porous pavement/ recharge bed installations in Middle Atlantic State locations for over 12 years. Their porous pavement installations serve a range of building parking needs and customers include office centers, fast food restaurants, libraries, and condominiums. Areas covered range from 3,000 to 147,000 square feet.

Experience has shown that most porous pavement failures occur because of a lack of erosion/ sediment control during construction. In many instances, contractors, unfamiliar with *what* they were doing and *why* they were doing it, allowed substantial quantities of sediment to erode onto the pavement surface after installation. Construction traffic also tracks heavy loads of clay particles onto the surface. Void spaces in the porous asphalt became permanently clogged, preventing stormwater from even entering the recharge bed below.

The fine particle silts which managed to pass through the porous pavement and through the underlying rock-filled recharge beds then settled out on the recharge bed bottom, reducing the recharge bed ability to infiltrate over time. These failures have made stormwater management program regulators and administrators generally very reluctant to recommend porous pavement as a BMP, rejecting

Figure 21.1: A typical porous pavement/recharge bed design



Source: **Cahill Associates**

the technology as impossible to apply in the real world.

Success have been frequently demonstrated, however, when project designs have adhered to the following guidelines. Importantly, these specifications add only marginally to total project costs.

- **Site conditions such as permeability of the soil must be verified.** Field verification of a soil layer of reasonable thickness (4 feet or more) with acceptable drainage qualities (percolation rate of 0.5 inches per hour or more) is essential. The most cost effective method of field testing will vary with each site and its geological complexity.

- **All sediment-laden runoff must be directed away from the porous pavement/recharge bed.** Total site design and stormwater drainage planning must be tailored to porous pavement/recharge bed requirements. While all runoff from impervious surfaces (roof tops, roads, parking areas, walkways, and so forth) should be directed onto the porous pavement and then into the recharge bed, pervious zones being re-landscaped after construction must be redirected away from the bed, or pretreated so as to eliminate sedimentation and resultant clogging. Strict erosion and sedimentation controls are a must.

- **Special safeguards/redundancies should be included in the porous pavement/recharge bed design.** Project success in part has resulted because of certain engineering features in porous surface/recharge bed design.

  (1) Selected filter fabric is placed generously on the floor and sides of the recharge bed after excavation/bed preparation, providing an inexpensive barrier between the stone-filled recharge bed and the soil mantle interface. This filter fabric allows water to pass readily, but prevents soil fines from migrating up into the rock basin, reducing the effective storage volume of the recharge bed.

  (2) In the event that the porous pavement were to become clogged, the edge of the porous paved area is designed to function as a linear overflow inlet around the perimeter of the parking bay. The inlet is accomplished quite simply by allowing a width of the bed around the perimeter to go unpaved, later to be topped off with a decorative river stone of some sort. Wheel stops are placed at the edge of the pavement, preventing vehicles from disturbing this emergency overflow.

  (3) Most intense traffic is directed away from porous surfaces. Porous surfaces are limited to parking areas receiving least wear and tear. Roadways ringing the parking areas receive conventional pavement, but drain into the recharge beds.

- **Communication with contractors is essential.** Contractors/workers involved with the project must understand what is being done and why compliance with specifications is essential. The nature and purpose of the porous pavement/recharge bed technique must be liberally entered onto the construction drawings and included within the written specifications for the project. Before construction, these specifications must be reviewed verbally and in person with contractors.

- **Installation must be supervised and spot-checked.** Proper inspection/supervision during construction of the porous pavement/recharge bed should be budgeted into all projects. Spot-checking by the engineer early on is essential. Regulatory agencies such as the local conservation district cannot be relied upon to make sure that plans and specifications are being executed fully. Contracts, bids, and budgets must include necessary inspection by the design engineer. A written record must be maintained including review and approval at critical project junctures, such as excavation of recharge beds, placement of filter fabric, and quality control at the stone crushing plant and asphalt mix plant. In addition, site inspection and supervision must make sure that construction vehicles are not allowed to traverse excavated recharge beds or enter the completed porous pavement, and that all erosion control measures are in place.

The edge of the porous paved area is designed to function

Cahill Associates and others recommend that completed porous pavement be vacuum-cleaned twice per year under normal circumstances, using commercially available pavement vacuuming equipment (either through vendor services or through outright purchase). Although many installations continue to function, in most cases this maintenance has not been performed, primarily because of a lack of communication between the contractor and site owner. Therefore in new projects, specifications include the requirement that site owner maintenance staff be given copies of porous pavement/recharge bed maintenance requirements for future use. Also required are permanent signs (one per parking bay; minimum of two per project) containing a short list of maintenance requirements. For educational value, signs can highlight major benefits of the installation.

The porous pavement/recharge bed BMP is not ideal for all developments and all sites. Clearly, if soils and geology do not allow for minimum necessary rates of infiltration, this type of stormwater management strategy makes no sense. The majority of upland soils in the eastern U.S., however, do have at least moderate infiltration capacities. In some coastal areas with excessively coarse sands, infiltration rates may be excessively rapid, and the recharge approach may need to be augmented with a peat liner for water quality reasons.

Environmental benefits of the porous pavement/recharge bed approach to stormwater management are compelling. As with any new technique, mistakes must be anticipated. However, if reasonable safeguards are taken, the porous pavement/recharge bed approach offers a uniquely elegant engineering solution for many sites as well as providing compelling environmental and cost savings advantages when compared with most other BMPs.

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Table 21.1: Ten tips for more successful porous pavement applications

1. Contract with a Design/Build Firm. These firms have the incentive to perform a careful and thorough job during each stage of design and construction.

2. Perform Detailed Geotechnical Tests at the Proposed Site. After further testing of soils and water table, as many as 25% of "ideal" sites are found to be inadequate for porous pavement. By catching these problem sites early, future problems can be avoided.

3. Only Consider if Client is Informed and Responsible. The owner of a porous pavement site plays a key role in maintaining and operating the BMP. Large corporate office park clients are ideal as they often continuously own and manage both the practice and the property over several decades.

4. Design a Perimeter Stone Filter Inlet as a Backup. Extending the stone filter course several feet outside the perimeter of the porous pavement provides a cheap and reliable means of getting runoff into the stone filter chamber in the event that the porous pavement ever clogs.

5. Utilize a Choker Layer of Stone in the Filter Course. The stone reservoir is normally constructed with a top layer of 1/2 inch gravel over a bottom layer of larger 1.5 to 3.0 inch stone. To avoid uneven surfaces, it is helpful to add a thin "choker layer" of fine gravel between the two layers of stone.

6. Overlap Filter Fabric on Sides During Construction. By generously extending filter fabric above the surface of the porous pavement (and staking it to adjacent pervious areas) an extra measure of sediment protection can be achieved during construction.

7. Pave Roads and Intensively Traveled Areas with Conventional Pavement. Heavily travelled areas tend to clog more rapidly. Therefore, these areas should be conventionally paved, and then graded to drain over to adjacent porous pavements.

8. Use Terraces of Porous Pavement on Sloping Sites. Porous pavement can be used on moderately sloping sites, if a series of stone reservoirs are used in an terrace-like arrangement.

9. Avoid the Use of Porous Pavement in Hydrocarbon Hotspots. Gas stations, truck stops and industrial sites are poor choices for porous pavement, given the higher risk that pollutant spills could enter groundwater.

10. Direct Runoff from Pervious or Exposed Areas Away from Pavement. It is critical to keep sediment away from porous pavement both during and after construction. This can be accomplished by grading adjacent pervious areas to drain away from the parking area and maintaining extensive sediment controls during construction.

Technical Note 22

Loss of White Cedar in New Jersey Pinelands Linked to Stormwater Runoff

One of the impacts of suburban stormwater runoff in the New Jersey Pinelands is the conversion of classic Atlantic white cedar wetlands to swamps dominated by hardwoods. Researchers Ehrenfeld and Schneider (1990, 1991) documented the link between human disturbances and vegetative changes at a series of wetland sites defined by differing levels of suburban intrusion. Importantly, they found that cedar wetlands directly influenced by stormwater runoff were much more strongly altered than all other wetland sites.

The cedar swamp is a unique habitat and serves as home to many rare and endangered plants and animals. In New Jersey and other states in the mid-Atlantic region, this habitat is typified by a nearly monospecific canopy of Atlantic white cedar with perhaps small amounts of several deciduous species including red maple, black gum, and sweetbay magnolia. The understory usually contains a variety of shrub species and the undulating swamp floor is carpeted with *Sphagnum spp*. The cedar swamp is a stressful environment, combining extreme acidity with low nutrient availability. The conditions result in a sensitive plant community with low diversity structure.

Virtually all water entering these wetlands is derived from infiltration in the uplands. This tight hydraulic connection assures that upland development will impact the quantity and quality of the water. Constituents of concern include nutrients, chloride, heavy metals, and organic chemicals from sources such as septic systems, lawns, and road surfaces. In addition, impervious surfaces reduce groundwater recharge and influence the seasonal dynamics of the water table. Drainage ditches, and stream channelization also can act to change wetland hydrology.

Cedar wetlands directly influenced by stormwater runoff were much more strongly altered than all other wetland sites.

Ehrenfeld and Schneider defined four groups of sites within the Pinelands to represent a gradient of suburban impact.

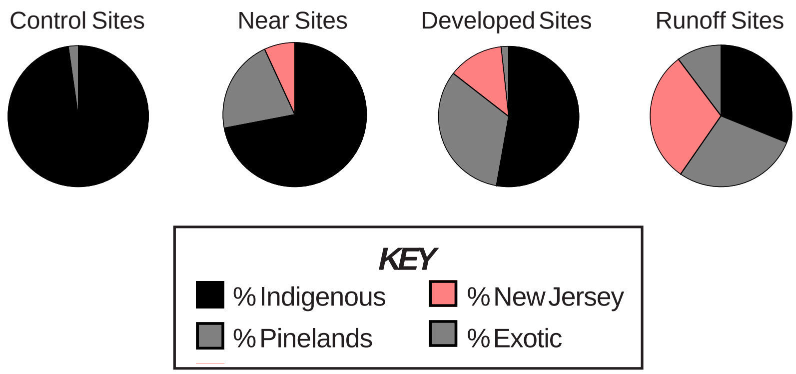
- *Control sites* were located within undisturbed watersheds and completely isolated from engineering features associated with development.
- *Near sites* were proximate to, and upstream of, unpaved roads within undisturbed watersheds.
- *Developed sites* were located within suburban developments with septic systems present along the wetland edge.
- *Runoff sites* were located in developed areas, and had stormwater sewer outfalls directly to the wetland.

Each individual site chosen for the study (four to five within each group) had a closed canopy of white cedar and was sampled for hydrologic, water quality, species composition, and community structure. Table 22.1 presents water quality data

Table 22.1: Mean water quality parameters measured during the growing season at the four site types. Sample sizes in parentheses. *(Adapted from Ehrenfeld and Schneider, 1991)*

Parameter	Control	Near	Developed	Runoff
Ammonia (µg/l)				
Surface water	3.9 (38)	2.2 (46)	141.3 (18)	229.4 (54)
Ground water	42.1 (50)	98.4 (50)	506.2 (48)	583.3 (60)
Orthophosphate (µg/l)				
Surface water	14.4 (64)	12.5 (88)	7.6 (24)	55.0 (92)
Ground water	11.0 (80)	12.7 (100)	30.9 (72)	68.0 (98)
Chloride (mg/l)				
Surface water	4.71 (40)	6.25 (46)	6.93 (18)	12.99 (54)
Ground water	4.93 (50)	7.04 (50)	16.4 (50)	15.4 (60)

Figure 22.1: Percentage of plant species from different habitats within each site type. *(Ehrenfeld and Schneider, 1991)*



from each of the groups.

Species composition in cedar wetlands is highly sensitive to development. As part of the study, the researchers classified all species observed into four habitat categories: *indigenous* to cedar swamps; found in other *Pineland* habitats; found in non-Pineland habitats in *New Jersey*; and *exotic* to the state. As shown in Figure 22.1, the control sites were highly dominated by species indigenous to cedar swamps. However, as development impacts progressed, indigenous species were dramatically displaced by species not traditionally associated with cedar swamps. Thus, cedar swamps impacted by development gradually lost species that define their uniqueness.

Reproduction of white cedar itself proved especially sensitive to development stress. Cedar stands in the Pinelands are typically even-aged, reflecting establishment after a large-scale disturbance such as fire, extensive windthrow, or clearcutting. As seen in Figure 22.2, mean densities of white cedar seedlings were greatly reduced in the developed and runoff sites. The implication is that when the next large-scale disturbance occurs, the current stands will not be replaced by new cedar growth.

This decline in cedar seedlings may be directly related to the decline in Sphagnum in these sites. Sphagnum is the most common substrate on which cedar reproduction is generally found and holds a large reservoir of buried viable seed. Unfortunately, the plant is especially sensitive to chloride, trampling, hydrological changes, elevated nitrogen concentrations, and other consequences of suburban development. Thus, the loss of the carpet of Sphagnum in a cedar swamp may foreshadow the eventually loss of the cedar trees themselves when a large-scale disturbance decimates the stand. The decline of Sphagnum cover as a result of increasing runoff is shown in Figure 22.3.

In summary, the study shows that protecting the integrity of white cedar wetlands requires careful planning to reduce suburban influences. Runoff must be diverted away from the cedar swamp and a buffer area maintained. The health of the Sphagnum in a particular swamp can potentially be used as an indicator of the future viability of the stand of white cedar.

—JS

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Figure 22.2: Mean densities of white cedar seedlings per square meter for each site type. *(Ehrenfeld and Schneider, 1991)*

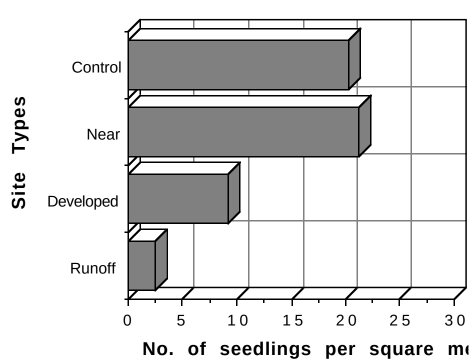
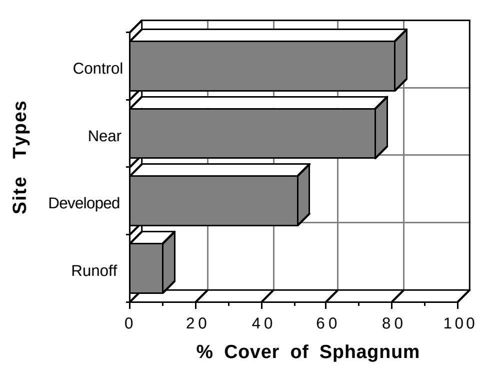


Figure 22.3: Mean percent cover of Sphagnum for each site type. *(Ehrenfeld and Schneider, 1991)*



Technical Note 23

Practical Tips for Establishing Freshwater Wetlands

No shortage of books and manuals exist to design freshwater wetlands for mitigation, restoration or stormwater treatment. A recent series of articles by Garbisch and others, however, suggest that successful establishment of freshwater wetlands often hinges on writing practical and thorough construction specifications for the contractor who implements the design. Lack of attention to these important details can lead to serious problems in establishing a dense and diverse freshwater wetland.

Ed Garbisch founded the nonprofit corporation **Environmental Concern** (EC) in 1972 to educate, research, develop, and apply technology for the restoration and construction of wetlands. Over this period, EC has been involved in hundreds of tidal and non-tidal wetland establishment projects and has gained a great deal of experience in wetland propagation and creation techniques. Some of practical lessons they have learned on how to construct successful wetlands are summarized in Table 23.1.

Matching the design hydrology of the planned wetland with the appropriate wetland plant species is perhaps the most critical task in the design of diverse pondscapes. However, many wetland construction drawings fail to even show the design hydrology on the plan. Without a good understanding of the future water surface elevations and the frequency of inundation it is nearly impossible make the right match. Therefore, it is important to clearly show design hydrology on all construction drawings, both in plan view and cross section.

Matching design hydrology with appropriate wetland plant species is perhaps the most critical task in planning diverse pondscapes.

Another frequently encountered problem is that while the planting plan may contain an extensive wetland plant list, most of the species may not be available in quantity from local wetland nurseries at the time of construction. As a consequence, plant species are substituted at the last minute that may

***Table 23.1: Useful Construction Specifications for Freshwater Wetlands* (adapted from Garbisch, 1993, 1994)**

1. Always clearly specify the proposed wetland hydrology on construction plans and drawings to ensure that proper wetland plants are selected. Be wary of wetland projects that only rely on groundwater for water supply.
2. Consider procuring wetland plants through growing contracts with wetland nurseries. These contracts ensure that the desired species and quantities of wetland plants will be available to implement the planting plan.
3. Use care before automatically requiring topsoil amendments to prepare the substrate for planned wetlands. Topsoiling may not always be needed, can be expensive and may introduce undesirable species from the seedbank.
4. Although it is very important to quickly stabilize disturbed upland areas during construction, avoid specifying the use of Tall Fescue for this purpose, because of its allelopathic character.
5. Be careful when specifying hydroseeding to establish stormwater and other types of wetlands without strong confidence that seeds will germinate and root in the substrate before the site is inundated. Otherwise, both mulch and seeds will float away or be unevenly distributed through the marsh.
6. If seeding is to be used as the key propagation method to establish the wetland, be sure to specify the quantity of pure live seed needed, the commercial source of seed, seeding technique, filler, and window and other key aspects leading to a successful result.
7. Clearly specify watering requirements during the first growing season for seasonally or temporarily inundated wetland areas. Drought conditions can severely reduce growth and survivorship for these wetlands without initial watering by truck or by a shallow aquifer well.

not meet the original intent of the wetland plan. A new approach has been developed to assure the species and quantities of wetland plants are available at the time of construction.

This approach is termed *contract growing*. It involves executing an advance contract with a wetland nursery to grow and deliver a specified number and species of plants at a future date. An up-front deposit of 20 to 30% is normally required prior to growing. While contract growing means more planning and logistics, the practice does provide a better guarantee that the planned and most desirable wetland plant species will be available when needed.

Contract growing assures that species and quantities of wetland plants are available at the time needed for construction.

Garbisch also questions the common specification to topsoil the surface of created herbaceous wetlands prior to planting. Topsoiling can be expensive, and may not always be needed at most sites. This is due to the fact that herbaceous wetland plants typically produce a great deal of below-ground organic matter and quickly dominate the composition of the substrate within a few years. Garbisch does suggest topsoiling in clay, rock, or pyritic soils and topsoiling or soil as well as soil ammendment for forested or scrub shrub wetlands. But generally soil tests should be performed before recommending topsoil at a particular site.

Most wetland plans devote a great deal of attention to the selection of wetland plant species, but give relatively little thought to the ground covers used to vegetate disturbed areas around the pond or wetland. Many plans simply specify that these areas be stabilized through hydroseeding of KY-31 Tall Fescue *(Festuca aruninacea)*. Fescue has been widely specified for years for erosion control during and after construction. It does an admirable job in quickly establishing a dense turf cover. This cool season bunch grass also tolerates a wide range of moisture conditions and can invade many areas of the site.

Burchick (1993) questions the wisdom of specifying Tall Fescue as a ground cover around wetlands and ponds. He argues that Fescue frequently displaces native grass and meadow species, out-competes natural or planted tree seedlings, and can even invade portions of the wetland. Fescue is a tough competitor partly due to its allelopathic characteristics. It secretes organic acids that can impair the germination of native species. Consequently, Burchick recommends that less aggressive cool season grasses be utilized for erosion control purposes around pond and wetland areas.

Direct seeding is often the most economical technique to establish wetlands. Garbsich cautions that construction specifications should be very tight if direct seeding is called for. For example, many wetland seed mixes have relatively low purity and germination rates. Consequently, Garbisch observes that if a pound of pure, live seed is needed to establish a ground cover per unit area, and it has a 10% germination rate and 50% purity, then some 20 pounds will actually need to be broadcast to achieve the desired coverage. Consequently it is recommended to express direct seeding rates in terms of pure, live seed (pls). The specifications should either require that the source(s) of the seed be indicated, or require that they be field collected and tested for purity and germination rate.

Of equal importance are the seeding *window* and *filler*. The window is the optimal seasons and dates for a successful result. The filler represents the sand dilution needed for small seeds to ensure they are uniformly distributed over the planting area. Seeding specifications should also clearly state the technique and implements for the seeding operation, and whether this operation will be done in the wet or the dry. Hydroseeding of wetlands should be avoided unless the contractor has confidence that the seeds will germinate and root before the next runoff event. Otherwise, the mulch, tack and seeds will float away or become unevenly distributed.

The establishment of a dense and diverse wetland is the joint product of the design engineer, landscape architect, wetland nursery, and planting contractor. Thoughtful and clear construction specifications help assure that each individual performs their role well.

—TRS

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Garbisch, E. 1994. The do’s and don’ts of wetland planning. Wetland Journal. 6(1): 16-17.

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Editors Note: Subscriptions to the quarterly *Wetland Journal* are available from Environmental Concern for $30 per year.

Technical Note 24

Broad-leaf Arrowhead: A Workhorse of the Wetland

The broad-leaf arrowhead *(Sagittaria latifolia)* is a native North American wetland plant found in southern Canada and much of the United States. Many practitioners have found it especially useful for wetland enhancement, restoration, and creation projects because of several desirable characteristics. Marburger (1993) points out, however, there is still much to be learned about its ecology and physiology before routinely investing in large scale planting and management schemes.

The plant is identified by its rosettes of arrowhead-shaped leaves. Flowers are white with three petals and arranged in whorls around a long stalk. Its most distinctive feature is the starchy tuber produced from the rhizomes. This phenomenon gives rise to its common name of *duck potato*. This "potato" portion of the plant is consumed by muskrats, porcupines, geese, and other animals. Native Americans and European settlers also used the tuber as a food source.

Adapted from Fassett, 1960

While its days as human food have long since past, other beneficial characteristics of broad-leaf arrowhead have propelled it into the field of wetland restoration. Special characteristics include the following.

1. **Adaptation to a wide range of conditions.** The plant persists under stabilized water levels of less than 50 cm and few drawdowns and survives in pHs from 5.9-8.8. It has been found in highly calcareous water and in a variety of soil types including sandy loams and silty clays. While it can withstand turbid conditions, it does not tolerate severe sediment deposition.

2. **Nutrient uptake.** Arrowhead rapidly takes up phosphorus from the sediments and retains it in its tissue. In one South Carolina study it had the highest leaf tissue composition of phosphorus of 17 wetland plants analyzed (Boyd, 1970). For this reason Arrowhead is often selected for use in municipal and domestic wastewater treatment systems, constructed wetlands, and for stormwater runoff treatment.

3. **Heavy metal uptake.** In surveys in South Carolina and Michigan, broad-leaf arrowhead was found to have the highest leaf dry weight concentrations of several metals.

4. **Ease of plant propagation.** Wetland plant vendors can supply achnenes, tubers, and container-grown plants. Tubers are generally preferred because they require less site preparation. Plants are more costly, but survive a wider range of initial conditions.

5. **Resistance to disease and damage.** There are few reports of population reductions due to pathogens, insect pests, and animal feeding. In some limited situation it may be necessary to enclose areas with protective fencing to keep out muskrats and waterfowl.

Arrowhead rapidly takes up phosphorus from the

In spite of many apparent field successes, Marburger points out there exists only a limited data base on the installation and management of the broad-leaf arrowhead, especially for large-scale applications. Before incorporating the arrowhead in a wetland design the practitioner needs to work with plant vendor to identify:

- If the environmental factors at the site are more favorable for germinating/growing achenes, tubers, or seedlings;
- If environmental factors are right for sustaining a mature population of arrowheads; and
- If pathogens, animal herbivory, and/or other plant species are likely to impact the plant.

—JS

References:

Boyd, C.E. 1970. Chemical analyses of some vascular aquatic plants. Archiven für Hydrobiologie 67:78-85.

Fassett, N.C. 1960. A manual of aquatic plants. The U. of Wisconsin Press, 405 pp.

Marburger, J.E., 1993. Biology and Management of *Sagittaria latifolia* Willd. (Broad-leaf Arrow-head) for Wetland Restoration and Creation. Restoration Ecology 1(4) 248-257.

Technical Note 25

Is Rooftop Runoff Really Clean?

Three recent papers investigated the quality of runoff from different roof surfaces. Conventional wisdom holds that roof runoff is relatively clean. Its use as drinking water in rainwater cistern systems is well known in many parts of the world. In other regions, stormwater managers maintain that cleaner roof runoff should be treated differently than runoff from dirtier parking lots and roadway areas. This view is supported by extensive monitoring data for several conventional pollutants such as sediment, nutrients, organic matter, and possibly bacteria.

The perception that roof runoff is always a source of relatively clean water may not always hold true when industrial roof surfaces are considered.

According to recent studies, however, rooftop runoff is not cleaner with respect to dissolved and particulate metals such as copper, lead, and especially zinc. Thomas and Greene (1993) sampled stormwater runoff from two kinds of roof surfaces at urban and industrial areas in Armidale, New South Wales (Australia). Good (1993) monitored runoff from five different roof surfaces in a sawmill /wood processing plant on the coast of Washington. Bannerman and his colleagues (1993) examined roof runoff samples from residential, commercial, and industrial sites in Wisconsin.

Monitoring results are compared in Table 25.1. As shown, industrial roofs had zinc levels that were two to 20 times greater than other urban source areas and often exceeded acute toxicity for aquatic life. It appears that galvanized roofing materials are a prime source of zinc in the urban landscape. Roofing materials, paints, and coatings are also suspected of being important sources of copper and lead as well. Roofs with copper flashing were found to have copper and lead concentrations up to 6 to 8 times greater than galvanized roofs.

Good (1993) also conducted toxicity studies on roof runoff from the industrial site in Washington and found that several samples were acutely toxic to rainbow trout in bioassays. The toxicity was attributed to the rapid corrosion of galvanized metal roofs and the leaching of zinc and other contaminants. It was also thought that tar-covered roofs were a source of copper. Although Good's study only looked at the first flush of runoff from rooftops, there was some evidence that toxicity remained high for up to three hours after the start of a storm.

Table 25.1: Metal concentrations in stormwater runoff from different roof surfaces in Australia, Washington, and Wisconsin. **(Concentrations in µg/l)**

Ref.	Land Use (N)	Roof Type	Copper	Lead	Zinc
2	Industrial (1)	Rusty Galvanized	20	302	12,200
2	Industrial (2)	Old Metal Roof (a)	11	10	1,980
2	Industrial (1)	Plywood W/Tar Paper	166	11	877
2	Industrial (1)	Tar Roof w/Aluminum Paint	25	10	297
2	Industrial (1)	Anodized Aluminum	16	15	101
3	Industrial (8)	Galvanized Iron	ND	~100	~3,600
3	Industrial (8)	Concrete Tile	ND	~90	~1,600
3	Urban (8)	Galvanized Iron	ND	~10	~50
3	Urban (8)	Concrete Tile	ND	~50	~200
1	Residential (18)	Shingles w/ Gutters	15	21	149
1	Commercial (3)	Flat Roof	9	9	330
1	Industrial (3)	Flat Roof	6	8	1,155
	All (2,300)	Stormwater Runoff	3	140	160

Taken together, the studies suggest that the perception that roof runoff is always a source of relatively clean water may not always hold true when industrial roof surfaces are considered. Galvanized roof coatings, in particular, appear to a major source of zinc and other metals in the urban landscape.

The rooftop monitoring studies raise the intriguing possibility that the use of alternative roofing or roof coating materials could result in lower pollutant loadings. Thus, a pollution prevention approach that avoids or minimizes the use of metals in roofing materials could be an attractive solution. Further research into metal loading from urban roof surfaces will be helpful in designing these new roof surfaces.

—TRS

References:

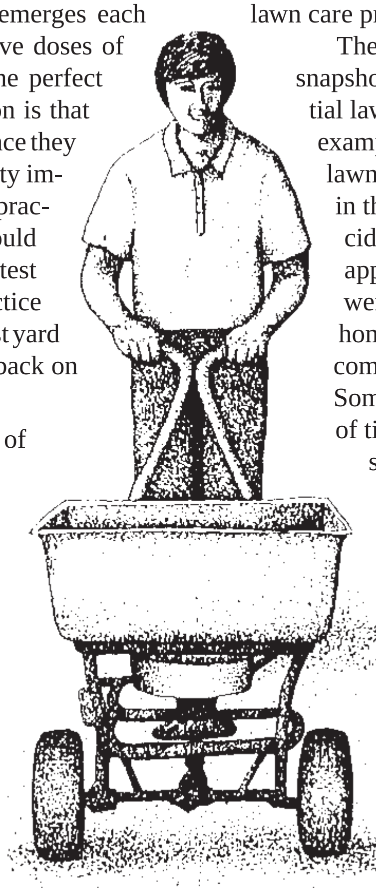
1. Bannerman, R. 1994. Sources of urban stormwater pollutants defined in Wisconsin. Technical Note 15. Watershed Protection Techniques. 1(1): 30-31.
2. Good, J.C. 1993. Roof runoff as a diffuse source of metals and aquatic toxicity in stormwater. Water Science Technology. 28 (3-5): 317-322.
3. Thomas, P.R. and G.R. Greene. 1993. Rainwater quality from different roof catchments. Water Science Technology. 28 (3-5) pp. 291-297.
4. U.S. EPA. 1983. Results of the nationwide urban runoff program. Vol. 1, Final Report. Washington, D.C. 200 pp.

Technical Note 26

Homeowner Survey Reveal Lawn Management Practices in Virginia

The nonpoint source community tends to make two assumptions about the link between lawn care and water quality. The first is that an army of envious suburban homeowners emerges each weekend to apply ever more massive doses of fertilizer and pesticides to create the perfect green sward. The second assumption is that this army would quickly surrender once they were informed about the water quality impacts of their excessive lawn care practices. So much the wiser, they would accurately calibrate lawn spreaders, test their soil prior to fertilization, practice integrated pest management, compost yard wastes, and recycle lawn clippings back on their yards.

As it turns out, recent surveys of suburban lawn care practices in Northern Virginia suggest that both assumptions are overly simplistic. Through an innovative residential water quality program, Marc Aveni and his colleagues at the Prince William Cooperative Extension have conducted detailed surveys of actual lawn care practices in Prince William County, Virginia. The County, situated to the southeast of Washington D.C., has experienced rapid suburban growth in the last 15 years. Aveni surveyed 100 homeowners on their lawn care practices, before and after they had enrolled in a demonstration residential lawn care program.



The pre-survey provides a revealing snapshot of current residential lawn care practices. For example, 79% of suburban lawns had been fertilized in the past year. Pesticides had also been applied to 66% of the lawns. Chemicals were typically applied by the homeowner, rather than lawn care companies (85% vs. 10% of all lawns). Some homeowners spent impressive sums of time and money on their yards—35% spent in excess of $100 on chemicals per year and labored on their lawns for more than four hours per week. A majority of homeowners (65%), however, spent less than $100/year on lawn chemicals and worked three hours or less each week.

The survey revealed that 79% of suburban lawns had been fertilized in the past year.

Less than 20% of residents tested their soil to determine whether their yard actually needed fertilization. Similarly, lawn owners were equally split as to the best season to apply fertilizer (Spring and Fall). Residents showed relatively little interest in non-chemical lawn care practices, such as turf aeration and dethatching—fewer than 30% of suburban lawns received such treatments. Nearly 50% of homeowners watered their lawns on at least a weekly basis in the summer.

Less than 20% of residents surveyed tested their soil to determine whether or not their yard actually needed fertilization.

Homeowners consulted a wide range information sources to guide their lawn care efforts. Their number one information source was product labels on the shelf, followed by newspapers and magazines, the advice of the hardware store or nursery clerks, and the wisdom of their friends and neighbors. Their least common information source, to Aveni's dismay, were unbiased lawn experts such as the Cooperative Extension Service.

While developing an outreach program to improve residential lawn care practices, Aveni quickly noted two important facts.

- Most residents were at least somewhat aware and concerned about the links between lawn care and water quality. However, most did not have much time to learn about better lawn care practices.
- While homeowners are often willing to adopt lawn practices that improve water quality, they still want a sharp looking lawn.

With support from the Extension Service, U.S. Department of Agriculture, a practical public education program was instituted in Prince William County that utilized the concept of neighborhood demonstration lawns. The concept works as follows. Interested individuals are recruited from Extension-sponsored field days where water-quality oriented lawn care practices are demonstrated. Each recruit is given short but intensive training on how to implement the recommended lawn care practices.

Over the course of the next year, an expert "Master Gardener" volunteer visits the homeowner to provide more one-on-one training and collect a soil test. After a year of practice and demonstrated understanding of the recommended practices, the homeowner's lawn may be designated as a demonstration lawn, with an attractive sign to pique neighborhood curiosity.

Post-surveys indicated that homeowners significantly changed both their attitudes and actual lawn practices as a result of participating in the demonstration lawn program. Sharp increases in soil testing, fall fertilization, pest identification, grass composting, and yard aeration were recorded, as well as sharp decreases in pesticide applications. Participants generally reported that the time and money they spent caring for their lawns stayed the same or declined. Most importantly, most homeowners in the program commented that the appearance of their lawn improved as a result of the program.

Aveni stresses the importance of understanding the sociology of nonpoint source pollution when advocating non-structural best management practices. Credible outreach programs must be based on a detailed knowledge of what homeowners actually do and why they do it. Nonpoint source education programs also must go beyond simple brochures to more intensive hands on training if they are to be effective.

—TRS

Contact:

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Reference:

A model lawn care guide is expected to be available in Fall 1994 from VA Cooperative Extension.

Technical Note 27

Groundwater Impacts of Golf Course Development in Cape Cod

Golf courses are a unique form of urban development in that they produce relatively little runoff but possibly a great deal of pollution. The unusually high rates of fertilizers and pesticides applied to tees, greens, and fairways (see Technical Note 20) have always made golf courses a prime water quality suspect. Until recently, however, no monitoring data was available to support or refute the argument that golf courses can contaminate groundwater.

Three years of detailed groundwater monitoring has recently been completed on four golf courses near Cape Cod, Massachusetts by Cohen and his colleagues (1990). Sandy soils in this coastal region contribute to a sole-source aquifer, so concerns about the quality of groundwater supplies are paramount. Each of the four golf courses were selected to represent the worst risk for possible groundwater contamination—each was underlain by

Table 27.1: Pesticides detected in golf course groundwater wells

Pesticide	Detection Rate
2-4-dichlorobenzoic acid (DCBA)	63%
Technical Chlordane *	44%
Total Dachtal residues	19%
Chlorothalonil	13%
Isofenphos	13%
Chloropyrifos	6%
Dicamba	6%
2-4-dichloro-phenol (2-4D)	6%

** banned on turfgrass since 1978*

sandy soils of glacial origin, had above normal pesticide and nutrient applications, and had been continuously operated for up to 30 years. Each of these three factors likely promote greater movement of pollutants in groundwater.

Three years of monitoring at 19 test wells detected 10 out of 17 pesticides (see Table 27.1). Most pesticides were present in low concentrations (less than 5 ppb), and were associated with greens and tee areas. The most frequently detected compound was DCBA, an impurity associated with herbicides. Technical chlordane was also frequently detected, despite the fact that its use on turfgrass had been banned since 1978. Chlordane is highly persistent, but relatively immobile in the soil environment (see Table 27.2), and appears to be leaching slowly into the groundwater in the 12 years since it was banned. With the exception of chlordane, no pesticide found in groundwater exceeded health guidance levels.

The monitoring study also tracked nitrate-nitrogen levels in the golf course groundwater (Table 27.3). Current golf course standards require that the soil medium underlying greens and tees be composed of at least 95% sand, so it is not surprising that nitrate levels were considerably elevated compared to non-golf course control sites. Maximum nitrate levels in excess of 10 mg/l were occasionally recorded, but averaged 1 to 6 mg/l. While the groundwater nitrate levels were thought to be no worse than reported for intensively fertilized agricultural areas, they are clearly high enough to create eutrophication problems in coastal or near coastal nitrogen sensitive waters.

The researchers found considerable evidence that nitrate leaching could be reduced through better fertilizer management. For example, Cohen *et al.* noted that the golf course (Falmouth) that utilized slow release fertilizers had sharply lower groundwater nitrate levels than all other sites. They also observed a significant decline in nitrate levels in years where fertilizer applications were below normal.

The researchers caution that the findings pertain to only one of many hydrogeologic settings, and more extensive groundwater monitoring in other regions is needed to fully define the water quality risks of golf courses. Southern courses, in particular remain a monitoring priority as their irrigation rates and nematicide and fungicide applications tend to be much greater than Northern courses.

The researchers found considerable evidence that nitrate leaching could be reduced through better fertilizer management.

Although much more monitoring needs to be done to fully assess the groundwater impact of golf courses, Cohen's study does reinforce the great potential for improved nutrient and pest management practices to protect groundwater at golf courses. Through relatively simple changes in how and when chemicals are used, golf course managers can help protect water quality and still provide an attractive and durable playing surface.

—TRS

References:

Cohen, S., S. Nickerson, R. Maxey, A. Dupuy and J. Senita. 1990. A groundwater monitoring study for pesticides and nitrates associated with golf courses on Cape Cod. Groundwater Monitoring Review. Winter 1990:160-173.

Petrovic, A. 1990. The fate of nitrogenous fertilizers applied to turfgrass. Journal of Environmental Quality. 19(1): 1-14.

Table 27.2: Relative mobility and persistence of selected pesticides *(Adapted from Cohen, et al., 1990)*

Mobility in Soil Environment

High Mobility	Medium Mobility	Low Mobility
2,4-D	Siduron	Chlordane
Dicamba	PCP	Heptachlor epoxide
Dachtal diacid	Iporodione	Dachtal
MCPP	Diazinon	Chlorothalonil
	Isofenphos	Chlorpyrifos
		Anilazine

Persistence in Soil Environment

High Persistence	Medium Persistence	Low Persistence
Chlordane	Dicamba	2,4-D
Siduron	Dachtal diacid	Dachtal
PCP	Iprodione	MCPP
Heptachlor epoxide	Diazinon	
	Isofenphos	
	Chlorothalinol	
	Chlorpyrifos	
	Anilazine	

***Table 27.3: Nitrate-nitrogen levels in groundwater of four golf courses in Cape Cod, Mass. All values in mg/l* (Adapted from Cohen, et al., 1990)**

Golf Course	Green	Tees	Fairway	Reference Site	Maximum Value (d)
Bass River	2.79	1.03	4.16	8.0 (b)	10.0
Eastward Ho!	6.31	1.0	6.66	0.10	30.0
Falmouth (a)	2.44	1.54	ND	0.10	6.5
Hyannisport	5.82	2.24	3.24	0.10	10.2
MEAN	4.34	1.45	4.68	0.10 (c)	—

(a) Falmouth course utilized slow release fertilizers during study.
(b) Background reference site appears to have been contaminated.
(c) Mean computed without outlier.
(d) Recorded from green, tee, or fairway well.

Technical Note 28

First Flush of Stormwater Pollutants Investigated in Texas

The concept of the first flush was first advanced in the early 1970's. Runoff sampling methods of this era required the collection of multiple flow and water quality samples over the duration of a storm event. As researchers examined monitoring data during storms, they discovered that pollutant concentrations tended to be much higher at the beginning of a storm compared to the middle or the end of the event.

> For certain pollutants, such as nitrate, copper, ortho-phosphorus, bacteria, and sediment, the first flush phenomena effect is weak or absent altogether.

It was reasoned that the store of pollutants that had accumulated on paved surface in dry weather quickly washed off during the beginning of the storm. Although runoff rates were greater at the middle and tail end of a storm, the store of pollutants available for washoff was depleted, and consequently the concentration of pollutants declined.

Stormwater managers quickly grasped the practical significance of the first flush phenomenon. If most of the urban pollutant load was transported in the beginning of a storm, then a much smaller volume of runoff storage would be needed to treat and remove urban pollutants. After further monitoring and modeling, the half inch rule was advanced. Essentially, the rule stated that 90% of the annual stormwater pollutant load was transported in the first half inch of runoff.

Many communities adopted this simple standard as the basis for providing water quality control in developing areas—size your BMP to capture the first half inch of runoff, and you will treat 90% of the annual pollutant load. Other communities modified the treatment standard further, by requiring that BMPs only capture the first half inch of runoff produced from impervious areas of the site.

With the advent of sophisticated automated sampling equipment to measure stormwater runoff in the 1980's, entire storm events could be represented by a single composite sample-known as the event mean concentration (EMC). One consequence of this technological advance was that researchers were no longer analyzing multiple samples during storms, and therefore, could not examine the behavior of pollutant concentrations during individual storm events. Further research into the first flush waned, and the half-inch rule became somewhat an article of faith in the stormwater community.

Recent analysis by Chang and his colleagues (1990), however, suggests that both the first flush phenomenon and the half-inch rule may not always hold true. Chang analyzed pollutant concentration data from over 160 storm events at seven urban runoff monitoring stations operated by the City of Austin, Texas from 1984 to 1988. The entire dataset was divided into different runoff increments (0 to 0.1 inch, 0.11 to 0.2 inch and so on). For purposes of his analysis, Chang conservatively defined the first flush as the first tenth of an inch of runoff. The pollutant concentration during the first flush was then compared to the pollutant concentration during the entire runoff event (EMC).

The results of the analysis are shown in Table 28.1. Shaded cells in the table indicate situations where the first flush phenomena did not occur (i.e., the storm EMC either greater than or equal to 90 percent of the first flush concentration). As can be seen, the first flush effect is most pronounced for sites that are highly imperviousness, but is much weaker at lower levels of imperviousness (5 to 30%). For certain pollutants, such as nitrate, copper, ortho-phosphorus, bacteria and sediment, the first flush phenomena effect is weak or absent altogether.

If the first flush effect is not as strong and universal as previously thought, should it still be used as a basis for determining the volume of stormwater treatment? To answer this question, Chang performed additional modeling to determine the proportion of the annual pollutant load that would be captured under the half-inch rule (Table 28.2).

The analysis does suggest that the half-inch rule works effectively for sites with less than 50% impervious cover for most of the stormwater pollutants examined. However, above this threshold, the rate of pollutant load capture drops off sharply. On average, only 78% of the annual pollutant load is captured for sites with 70% impervious cover, and a mere 64% for sites with 90% impervious cover.

To put these results into perspective, consider a BMP designed under the half inch rule on a 90% impervious site. Further assume that the BMP removes, on average 50%, of the pollutants that it captures. The net annual pollutant removal rate for the BMP, however, would only amount to 32% since a large fraction of the annual pollutant load is never captured by the BMP. The clear design implication is that the half-inch BMP sizing rule is not adequate for sites with high impervious cover. Communities that still utilize the half-inch rule may wish to consider other BMP sizing alternatives.

The clear design implication is that the half-inch sizing rule is not adequate for sites with high impervious cover.

One alternative technique to size urban BMPs involves basing the required treatment volume on the runoff produced from a larger storm (e.g., the 1.25 inch rainfall event) using a simple runoff coefficient. This method results in a greater treatment volume as impervious cover increases, and therefore, should avoid the key deficiency associated with the half-inch rule.

—TRS

Source:

Chang, G., J. Parrish and C. Souer. 1990. The first flush of runoff and its effect on control structure design. Environ. Resource Mgt. Div. Dept. of Environ.and Conservation Services. Austin, TX.

Contact:

Dr. George Chang. Environmental Resource Management Division. Department of Environmental and Conservation Services. City of Austin, Texas. (512) 499-2088

Figure 28.1: First flush concentration as a function of imperviousness. (Mean concentration in mg/l of first tenth of an inch of runoff) **(Adapted from Chang, et al. 1990.)**

Polutant	5% Imp.	30% Imp.	50% Imp.	70% Imp.	90% Imp.
BOD (5-day)	9	10	14	16	19
COD	26	52	65	66	69
Total organic C	7	13	14	18	24
$NO_3 + NO_2$	0.15	0.71	0.52	0.55	0.67
Total Kjeldahl N	0.52	0.91	1.10	1.24	1.40
Ammonia	0.09	0.24	0.38	0.30	0.24
Phosphate	0.04	0.22	0.20	0.20	0.20
Total solids	80	170	212	220	123
Copper	0.01	0.01	0.01	0.01	0.01
Iron	0.36	0.68	0.48	0.54	0.58
Lead	0.004	0.045	0.03	0.04	0.06
Zinc	0.008	0.060	0.090	0.12	0.17
Fecal Coliform	9	39	28	28	31
Fecal Strep	9	30	27	27	30

Cells are shaded to indicate when the event mean concentration is within 90% of the recorded first flush concentration

Table 28.2: Percent of annual pollutant load captured using the half-inch rule as a function of site imperviousness. **(Adapted from Chang, et al. 1990.)**

Pollutant	10% Imp.	30% Imp.	50% Imp.	70% Imp.	90% Imp.
BOD (5-day)	100	93	86	80	70
COD	100	97	86	80	79
Total organic C	100	94	83	82	78
$NO_3 + N0_2$	100	91	84	79	72
Total Kjeldahl N	100	90	87	80	73
Ammonia	100	96	88	76	61
Phosphate	100	91	81	77	73
Total solids	100	81	75	53	43
Copper	100	93	80	76	74
Iron	100	99	81	84	66
Lead	100	99	94	83	81
Zinc	100	98	87	84	68
Fecal Coliform	100	93	83	77	62
Fecal Strep	100	91	82	756	5

BOOKS

■ **Landscape Restoration Handbook.** 1993. Harker, D., S. Evans, M. Evans and K. Harker. CRC Press, Inc., Boca Raton, FL. 661 pp.

The cornerstone of this new book published as a cooperative effort between New York Audubon and the U.S. Golf Association is the concept of "Greenlinks." This term refers to a comprehensive program for naturalizing the landscape. A Greenlinks program is divided into three basic parts: (1) introducing a target audience to the idea of naturalizing the landscape through a strong education program; (2) working with adjacent and regional landowners to link greenspaces and natural area together in a regional context; and (3) developing a detailed naturalization plan for the managed site that includes a combination of ecological restoration and natural landscaping.

In addition to well-presented discussions of the principals and guidelines of Greenlink programs, practitioners will find especially valuable the lengthy appendices that provide the details needed for creating naturalized landscapes just about anywhere in the country. Included are descriptions and lists of plant species associated with dominant ecological communities found in 30 natural regions in the United States. To aid landscapers with selecting design specifications and appropriate species, the authors present matrices of woody and herbaceous species characteristics. A list of nurseries by state that carry native plants is also presented.

Naturalizing human-managed landscapes is a challenging task. This book provides land managers with the tools to get started.

—JS

CRC Press, Inc., 2000 Corporate Blvd., Boca Raton, FL 33431. ISBN 0-87371-952-2.

■ **Urban Wildlife Habitats: A Landscape Perspective.** 1994. L.W. Adams. University of Minnesota Press. Minneapolis, MN 185 pp.

This introductory text provides a good survey of current knowledge about urban wildlife. The author, Lowell Adams, Vice President of the National Institute for Urban Wildlife in Columbia, Maryland, cogently summarizes what we know and don't know about the wildlife that has adapted to our urban areas. The degree of adaptation to the urban landscape can be impressive. For example, Adams cites research that indicates that many raccoons den in storm drains pipes in the winter, birds of prey lurking over birdfeeders, and the preference of red foxes to travel along railroad corridors through urban areas. These generalists have all proliferated in recent years and include deer, beaver, squirrels, geese, mallards, pigeons, nighthawks, green frogs, armadillos and alligators. Perhaps the most dominant species in the urban environment, however, are cats and dogs. In highly developed areas, Adams notes that there populations can exceed 1 per acre. Cats, in particular, are efficient predators, and have been shown to dramatically reduce populations of chipmunks and mourning doves.

Adams points out that for each winner, there are numerous losers that cannot withstand the many stressors in urban environments, or the loss of specialized habitats. These include many forest interior dwelling birds, chipmunks, most fish and aquatic insect species, salamanders, tree frogs, and others.

The book concludes with some general recommendations on landscape planning, wildlife management, and pest control. He notes that use of many management options needs to be tempered by a keen understanding of the public's perceptions (or misperceptions) about wildlife.

—TRS

MANUALS, HANDBOOKS, GUIDANCE DOCUMENTS

■ **Wetland Planting Guide for the Northeastern United States—Plants for Wetland Creation, Restoration, and Enhancement.** 1993. Thunhorst, G. Environmental Concern, Inc., St. Michaels, MD. 179 pp.

Existing field guides, identification manuals, treatises on culture and growth, and other references provide the practitioner with pieces of the puzzle needed to create, restore, or enhance a wetland. But who has time for a literature review to identify the best wetland plants for each unique design job? A new publication from *Environmental Concern, Inc.*, a non-profit firm devoted to the research, development, and application of technology in the restoration and construction of wetlands, does the leg-work for you.

This soft-cover guide is a series of one-page fact sheets on trees, shrubs, herbaceous emergent plants, and submerged or floating aquatic vegetation that have been successfully used in wetland creation, restoration, and enhancement projects in the northeastern United States. (In this guide, northeastern United States is meant to include Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia, Virginia, Ohio, West Virginia, and Kentucky). The fact sheets present a line drawing and descriptive information concerning growth (rate of spread and method of vegetative reproduction), planting (suggested spacing and forms available), habitat (community, distribution, and shade tolerance), appearance (height and flowering/fruiting period), wildlife benefits (food and species served), and hydrology (indicator status, salinity, tidal zone, and nontidal regime).

The target audience for this publication is obviously wetlands designers. The clear, attractive, and technically-sound presentation of wetland plant information, however, make this a valuable "go-to" resource for anyone that works with or appreciates wetlands, even as a casual observer.

—JS

Environmental Concern, Inc., P.O. Box P, 210 West Chew Ave., St. Michaels, MD 21663. Tel. (410) 745-9620. ISBN 1-883226-02-3.

■ **Urban Runoff Management Information/Education Products.** USEPA, Region 5 Water Div., Wetlands and Watershed Sec., Watershed Management Unit and USEPA Office of Wastewater Enforcement and Compliance, Permits Div., NPDES Prog. Branch, Stormwater Sec. 1993.

Has it been done before? Are we recreating the wheel? How does a practitioner in Virginia find out what urban runoff public education products have been developed in California? Wonder no more—the U.S. Environmental Protection Agency has created a resource catalog specifically on information and education material relating to urban runoff, stormwater, and construction activities. Presented in a 3-ring binder format, this publication contains over 900 entries from all across the country.

EPA's purposes in compiling this material are to showcase existing efforts in the field and to help people become aware of what is available. Entries are organized by material type (e.g., booklets, books, catalogs, citizen's action guides, computer software and databases, newsletters/magazines, student activities, and videos). Each entry identifies the intended audience (e.g., children, general public, local government officials), provides a short description, and gives information on how the material can be ordered.

EPA plans to periodically update this catalogue and add material concerning technical, institutional, program, and policy issues. Readers are encouraged to review this notebook and provide EPA with appropriate additions.

—JS

Attn: Kimberly Ogden Hankins, OWEC (EN-336), U.S. Environmental Protection Agency, 401 M Street, SW, Washington, DC, 20460. Tel. (202) 260-8328.

■ **The Stream Protection Approach.** 1994. T. Schueler. Center for Watershed Protection. Silver Spring, MD. 66 pp. + appendices.

The Stream Protection Approach represents a new watershed management strategy for rapidly developing areas. The heart of the SPA approach is a comprehensive effort to protect key components of the stream ecosystem throughout the entire development cycle. The approach provides a coherent framework to organize environmental regulation over the entire development cycle. It recognizes that streams can only be protected when local governments make a strong commitment to do so. This involves the adoption of four key elements:

- an effective local stream protection institution;
- a strong and enforceable stream protection ordinance;
- a unified and comprehensive development review process; and
- technically sound performance criteria or standards for new development.

The report provides guidance to local officials and planners on effective methods to strengthen their programs. It begins by presenting the key features of effective local stream protection programs across the country. Next, it sets forth practical guidance on how to craft a local stream protection ordinance that is enforceable, equitable and responsive to the needs of the community. The third part presents tips to strengthen the local development review process, through a 12 step process of incentives and penalties. The final section provides examples of clear performance standards to govern the development process. Flexible performance standards are presented that protect key stream resource areas, minimize impervious area, regulate clearing, grading and erosion control, and provide stormwater control.

The Stream Protection Approach can help eliminate many of the complex and inflexible regulations that accumulate over time, as well as streamline the cumbersome and often redundant permit review processes. At the same time, it sets a high and measurable standard for efforts at each stage of the development process—the protection and maintenance of urban stream quality.

—TRS

Copies of the report can be ordered from the Center for Watershed Protection at $12.00 each.

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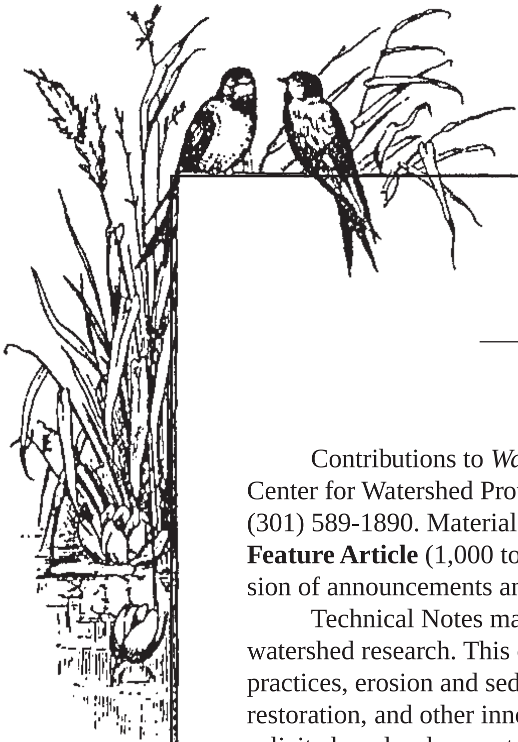

Instructions to Contributors

Contributions to *Watershed Protection Techniques* are encouraged and should be sent to Editor, Center for Watershed Protection, 8630 Fenton Street, Suite 910, Silver Spring, MD 20910. Telephone: (301) 589-1890. Material may be in the form of a short **Technical Note** (250 to 500 words), a longer **Feature Article** (1,000 to 2,000 words) or an opinion or comment in the **Open Forum** section. Submission of announcements and book reviews for the **Resources** section are also welcome.

Technical Notes may deal with any watershed protection or restoration technique, as well as basic watershed research. This can include such topics as the performance of urban stormwater management practices, erosion and sediment controls, created or restored wetlands, riparian reforestation, stream restoration, and other innovative environmental planning tools and techniques. In addition, Notes are solicited on developments in watershed research, such as urban stream and lake assessments, runoff monitoring, and the impact of urbanization on aquatic and terrestrial systems. Of particular interest are submissions that provide performance monitoring data, maintenance records, field surveys, or other quantitative assessments of a particular watershed tool or technique. Advances in understanding of aquatic ecosystems are also appropriate, provided they have a clear watershed protection or management application. Technical notes may describe a proprietary, licensed, or patented technology, as long as the note includes performance data and is not merely a marketing pitch.

Authors that wish to submit a longer feature article should contact the editor.

Manuscript Specifications

Send two copies of the typed manuscript (double-spaced) along with a 3.5 or 5.25 inch diskette of the text (WordPerfect 5.1 or equivalent). Each manuscript should include a brief but appropriate title, followed by the author(s) name, current mailing address, telephone number, and fax number. Footnotes are to be avoided. References should be listed in alphabetical order by author. Citations in feature articles should be consecutively numbered, whereas citations in Notes should include the author and year of publication.

In deference to engineers, English measurement units may be used. Metric equivalents are welcome. Both scientific names and common names for species should be supplied. Tables must be typed, double-spaced, with a complete title. Photographs should be sharp black and white glossy prints, mounted on backing board and mailed flat. Computer-generated charts and figures are acceptable if of laser printer quality. No manuscripts or figures can be returned unless a request to do so is made at the time of submission. Edited manuscripts will be forwarded to the Editorial Board for their review.

Style and Format

As *Techniques* is intended for a wide audience of planners, engineers, and biologists, the editor encourages the use of plain, concise style, free of unnecessary technical terms or acronyms. Numbers under ten should be written out. Authors should use the active voice whenever possible. Authors are also encouraged to supply physical, geometric, and climatic parameters to facilitate comparison to other regions of the country. Lastly, the goal of *Techniques* is to provide accurate, reliable, and practical information that can be readily applied by other watershed practitioners. Therefore, authors should make every attempt to present a condensed summary of practical design and planning factors that will make the technique work more effectively.